URS 669-6

AD 653 07

REPAIR AND RECLAMATION OF GAS AND ELECTRIC UTILITY SYSTEMS

Work Unit 3311B

July 1967

Prepared for

Stanford Research Institute
Menlo Park, California

Subcontract No. 11205(4949A-65)-US

and

Office of Civil Defense
Washington, D. C.

URS

CORPORATION

"This document has been approved for public release and sale; its distribution is unlimited."

140

URS 669-6

REPAIR AND RECLAMATION OF GAS AND ELECTRIC UTILITY SYSTEMS

Work Unit 3311B

Final Report

July 1967

by

William H. Van Horn
Gail B. Boyd
Carl R. Foget

URS CORPORATION
1811 Trousdale Drive
Burlingame, California

Prepared for

Stanford Research Institute
Menlo Park, California

Subcontract No. 11205(4949A-65)-US

and

Office of Civil Defense
Washington, D. C.

Summary
URS 669-6

URS CORPORATION

Summary Report

of

REPAIR AND RECLAMATION OF GAS AND ELECTRIC UTILITY SYSTEMS

Work Unit 3311B

Final Report

July 1967

by

William H. Van Horn
Gail B. Boyd
Carl R. Foget

URS CORPORATION
1811 Trousdale Drive
Burlingame, California

Prepared for

Stanford Research Institute
Menlo Park, California

Subcontract No. 11205(4949A-65)-US

and

Office of Civil Defense
Washington, D. C.

Summary Report

of

REPAIR AND RECLAMATION OF GAS AND ELECTRIC UTILITY SYSTEMS

OBJECTIVES

The objectives of this study of the gas and electric utility systems in metropolitan areas were as follows:

1. Analysis and identification of vital components and facilities of utility systems.

2. Estimation of the repair times and required manpower (in terms of effort and necessary skills) to repair facilities damaged by nuclear weapon effects.

3. Classification of required repair parts and materials into critical and noncritical categories.

4. Identification of any specialized construction equipment, tools, instruments, etc. necessary to carry out the repair effort.

5. Estimation, on a utility-wide basis, of the effort, materials, and most suitable approaches for the repair of damaged facilities.

6. Derivation of pertinent conclusions from the analysis of alternate sources for material critical to the recovery task.

PROCEDURE

The procedures followed were:

1. Detailed functional descriptions of "typical" gas and electric utility systems were developed with primary emphasis based on facilities located within the local or urban area.

2. The elements or components vital to the functioning of the utility system were identified and rated as to criticality, i.e., the element's functional contribution to the system's operation.

3. Damage to the various system elements was estimated for a wide range of weapon effects and intensities. All weapon effects were keyed to overpressure.

4. Repair time and effort requirements were estimated for each critical element of the system individually and then summarized to obtain the repair reclamation "cost" for the utility.

5. The results of the repair estimates were analyzed, and a mathematical model was developed to relate damage (expressed as overpressure) to repair effort (in man-days).

6. A "typical" city with "typical" gas and electric utility systems was used to assess the overall repair requirements for various levels of damage.

7. The time-phased repair effort was determined for each utility system, including requirements for manpower, (by skill) and supplies; alternate operating procedures which might alleviate constraints created by shortages of resources were also considered.

SIGNIFICANT FINDINGS

- Metropolitan gas utility systems, because they are primarily located below ground and are composed of few kinds of elements, all having great structural strength, are much less vulnerable to weapons damage than are electric utility systems, which are primarily above ground and consist of varied elements, many of which are easily damaged.

- Gas utility systems are relatively simple in design and operation and even when damaged require relatively small repair effort; electric utility systems are complex and interdependent, so that when damage occurs, repair requirements are high in terms of manpower, equipment, spare parts, and materials.

- The level of damage, expressed as overpressure, can be related to repair effort by an exponential function for which appropriate parameters are known. This matematical repair model can be used to predict repair requirements for various levels of damage for real utilities and real cities.

- Charts showing the time-phased repair effort, by skill classification, are presented for each of the utilities at two different levels of damage.

<u>Damaged Components and Continuity of Service</u>

At very low overpressures (1 to 2 psi) electric utility service would be temporarily disrupted immediately following the attack until such time as repair crews could make minor repairs on protective devices and the system converted to manual control, a matter of some hours if personnel are available. At overpressures of 3 to 4 psi, electric utilities would sustain moderate to serious damage to distribution systems (primarily from broken poles and trees falling across overhead lines), and large sections of the city would be without power for a matter of days or weeks. Transmission lines would be expected to sustain little damage. Failures might occur in the steam electric generating facility, primarily due to damaged control systems, but such failures would be of relatively short duration if repair crews were on hand and manual operation could be instituted. Further, power might be "imported" via interties from generating stations in unaffected areas. At somewhat higher overpressure levels (4 to 6 psi), all aboveground distribution systems and most of the transmission systems of the electric utility would be severely damaged and inoperable. Even with the massive repair effort, service over the entire city would be disrupted for a matter of weeks or months. Electric generating plants would sustain considerable damage, which would require, at a minimum, a repair effort of many months. Substations and switch yards would also be damaged to a considerable extent. Imported power from interties would not be usable until such time as transmission and distribution systems and substations within the city were repaired or rebuilt. At overpressure levels above 8 psi, the distribution and transmission systems of the electrical utility would be so severely damaged that rebuilding would be undertaken only in the most unusual circumstances; even the reuse of salvageable parts would be unlikely. The estimated repair effort for the "typical" utility and the "typical" city (400,000 persons) would be 171,000 man-days; this effort would require a minimum of 120 days and an average crew size of 480 men (3 shifts/day).

Interuption of service to gas consumers is unlikely to occur at low overpressures. The first major demand for repair services occurs at about 4 psi, when the failure of structures will break service connections, venting gas to the atmosphere; the gas utility then has the choice of either cutting off the supply at the consumers service connection (a most time-consuming effort) or cutting off entire service areas at district regulators (in extreme cases an entire city might have to be cut off from the gas supply of the city gate station). At 10 to 12 psi serious damage to aboveground gas pipe lines (such as river crossings) and appurtenances (such as city gate stations) would be widespread. However, with trained crews, equipment, and replacement parts, system integrity could be rather rapidly reestablished, although service to consumers (presumably in areas experiencing considerably less damage) could not be resumed until the affected portions of the system could be purged of air and tested. Extensive damage to the underground pipeline system would be expected to occur only where air-induced or direct ground shock is an important factor. Presently available data are insufficient to allow any reasonable estimate to be made concerning the occurrence and degree of damage resulting from such phenomena. Virtually no repair effort is required in the "typical" gas utility, in the "typical" city, at the 4 psi overpressure level, (disregarding any attempt to cap off each individual broken service connection); at 9 psi the estimated repair effort would be approximately 1050 man-days; repair time could be as short as 5 days using an average crew size of 75 men (3 shifts/day).

Adequacy of Supplies and Spare Parts

The probable postattack demand for replacement parts would be high, while their probable availability would be low. Certain critical elements appear to impose special constraints upon the restoration of the electrical utility in particular, these being large transformers, porcelain insulators, and small pole-mounted transformers.

Requirements for Manpower

It is probable that major shortages in some repair skills would occur even in the absence of personnel casualties. Consequently the interchanging of repair skills would probably be widely practiced. Repair effort is expected to roughly double where utility-trained crews are replaced with crews composed of workers having different but related skills. Within limits, skilled labor can be substituted for damaged components, and conversely, new components can reduce the requirements for skilled labor.

Requirements for Preattack Planning

Utilities, because of their frequent encounters with natural disaster, have some basic capability for meeting nuclear disaster. However, additional planning and training directed primarily at problems associated with nuclear attack would substantially increase the utilities' ability to remain in operation in the event of light damage and to resume operations more rapidly in the event of heavier damage. Since control equipment invariably fails prior to the main components of the system, personnel should maintain their skills in alternate techniques which permit manual control of operation.

ABSTRACT

This study for the Office of Civil Defense has been directed toward identifying the essential subsystems and components of metropolitan gas and electric utility systems, determining their functional relationships, estimating the damage to critical elements from various nuclear weapons effects, and estimating the repair requirements for restoring damaged systems. A mathematical repair model was developed and applied to a "typical" city, and from the results of this study, time repair effort, including manpower by skills, was derived. The major findings of the report are:

- Being located primarily below ground and comprised of elements having great structural strength, metropolitan gas utility systems tend to be much less vulnerable to weapon damage than electric utility systems. Further, gas system installations are generally less complex in design and function and, therefore, impose smaller and less stringent repair requirements in terms of manpower, skills, equipment, spare parts, and materials.

- The level of damage, expressed as overpressure (and related weapon effects) can be related to repair effort by an experimental function. This mathematical repair model can be used to predict repair requirements (including men and materials under various assumed attack conditions) for real utilities and real cities.

Other Findings Include:

- A shortage of skilled utility system workers could impose serious constraints on all phases of the postattack repair program, although some interchanging with related skills and substitution by a larger work force of semi-skilled workers would generally yield satisfactory repairs.

- Preattack planning directed toward inventorying and stockpiling critical repair resources, training utility employees to perform emergency repairs, and planning special shutdown and emergency protective procedures is recommended.

- Recommendations for future research include a quantitative determination of the interchangeability of labor skills, an investigation of the change in consumer utility demand following a nuclear attack, a study of the capability of the postattack economy to furnish the required utility replacement parts, and an extension of the present study to include nuclear power plants.

ACKNOWLEDGEMENTS

This study was conducted under the guidance of Mr. R. B. Bothun of the Civil Defense Technical Office at Stanford Research Institute, who as Technical Monitor provided us with valuable assistance and direction. The splendid cooperation of Edward J. Mahood of Kennedy Engineers and Peter Wilkinson and Edward Bennett, of Beamer/Wilkinson is acknowledged and appreciated.

The authors are grateful for the assistance of URS personnel who contributed to various sections of this study. Phillip Morris provided both guidance and input for the damage estimates and reviewed the final report. Dr. Alan McMasters provided valuable consultation in the development of the mathematical repair model. Miss Ann Willson evaluated much of the bulky data and was instrumental in deriving the repair model. James Zaccor provided helpful suggestions pertaining to the vulnerability of the underground portions of the gas system to nuclear attack.

Project manager was W. H. Van Horn; G. B. Boyd guided the analysis of the gas utilities and C. R. Foget that of the electrical utility. The entire effort was conducted under the supervision of M. B Hawkins, manager of the Environmental Technology Department.

FOREWORD

In this study of the vulnerability and repair of metropolitan gas and electric utility systems, URS provided overall direction, prediction of weapons effects, estimation of damage, and interpretation of results. Subcontractors provided data, technical support, and critical review, with major contributions in the areas of system definition and repair requirements and time-phasing. Kennedy Engineers of San Francisco, who specialize in municipal and utilities engineering, served as subcontractors on the gas utility phase. Beamer/Wilkinson and Associates of Oakland, California, electrical engineering consultants with experience in electrical distribution systems, were subcontractors on the electric utility phase and provided informal liaison with the utility industry when required. The Defense Electric Power Administration (DEPA) and the Office of Oil and Gas (OOG), which have been established to provide liaison between the electric and gas utilities and government and industry, were also contacted to obtain additional information on utility operations. The repair estimates were reviewed by two consultants having extensive operating experience. Mr. George A. Peers, former vice-president in charge of electrical operations for Pacific Gas and Electric, provided the review of the electric utility and Mr. Thomas P. Jenkins, a former division manager for the gas system of Pacific Gas and Electric, provided the review of the gas utility.

CONTENTS

CONTENTS (Cont)

ILLUSTRATIONS

ILLUSTRATIONS (Cont)

TABLES

Section 1
INTRODUCTION

The operation of public utilities following a nuclear attack is essential for the support of postattack emergency and recovery operations. Many necessary functions will be impossible to perform until damaged utility systems can be repaired and operation restored. Recognizing the importance of the services provided by public utilities, several organizations have undertaken studies in the past to determine the vulnerability of various utilities to nuclear attack. Also many public utilities have, on their own initiative, prepared survival plans applicable to their own systems. However, despite the availability of these various studies and plans, no general guidelines have been available for estimating the magnitude of the repair problem which might be faced by utility systems.

OBJECTIVES

The objectives of this study of the gas and electric utility systems of metropolitan areas are as follows:

1. Analysis and identification of the vital components and facilities of utility systems. This includes both the utility system equipment or plant and the key operating and maintenance materials -- lubricating oils, bearings, filters, and the like — required for continuous operation of the system.

2. The estimation of the repair times and the required manpower in terms of the necessary skills and the significant material requirements to repair facilities damaged by nuclear weapons.

3. Classification of the required repair materials and parts into categories, such as the following: a. absolutely necessary for repair; b. substitute materials or parts can be used; c. modification of operating procedures from preattack standards will eliminate any requirement.

4. Identification of any specialized construction equipment, tools, instruments, or other devices necessary to carry out the repair effort.

5. Generalization, on the basis of the cases studied, of the estimating methods developed and employed to provide suitable procedures to estimate on a utility-wide basis the effort, materials, and most suitable approaches for the repair of damaged facilities.

6. Derivation of pertinent conclusions from the analysis of alternative sources for material critical to the recovery tasks.

BACKGROUND

A number of studies have been made concerning the impact of nuclear weapons on electric utility systems and their components. The vulnerability of large steam electric generating plants has been analyzed by Armour Research Foundation (now IIT Research Institute—Ref. 1) and by Consoer, White, and Hersey (Ref. 2). Similar information for plants of the TVA system, including hydroelectric plants and dams, was investigated by Advanced Research, Inc. (Ref. 3). Typical components of transmission and distribution systems were tested in a field exercise at the Nevada Test Site in 1955 and are reported in Ref. 4. Electric utility systems are often subjected to natural disaster; a well-documented example is given by U.S. Naval Civil Engineering Laboratory (Ref. 5), which assessed the effects of the Alaskan earthquake on the utilities in the Anchorage area. Also, damage to electric generating plants due to rapid shutdown was considered in a recent SRI report (Ref. 6).

The Defense Electric Power Administration of the Department of Interior is responsible for assisting electric utility companies to prepare for national emergency and has issued a manual (Ref. 7) which discusses in a cursory manner elements in the protection of electric power systems. In a separate report (Ref. 8) DEPA assesses the capability of the major electric transmission networks and interconnections in the United States to supply power requirements after a moderate nuclear attack; this latter report concludes that because of interconnections, no major power shortages would occur. However, problems can arise from dependency on interconnections, as demonstrated for example, in the Northeast power failure of November, 1965 and the Missouri Basin power failure of January, 1965 (Ref. 9).

Probable effects of nuclear attack on a city's electric utility system were recently studied (in part by URS Corporation) in the Engineering Phase of the EOSD Study (Refs. 10, 11 and 12). This study predicted the damage to the components of the electric utilities in three cities and the probable capability of restoring the utility to a functioning condition. Other studies have been conducted (but not all reported) by the U.S. Naval Radiological Defense Laboratory, Research Triangle Institute, and Stanford Research Institute.

The literature related to the effects of nuclear attack on the gas utilities is quite limited. An American Gas Association paper (Ref. 13), although slanted toward conventional warfare, lists many protective and repair measures applicable to nuclear warfare situations and provides guidance for controlling and repairing blast damage to gas works and gas distribution systems. Two tests have been run at the Nevada Test Site on the vulnerability of components of gas utilities to nuclear blast. In the first test (Ref. 14) the damage to an LP gas installation was assessed, and in the second test (Ref. 15) the damage sustained by typical natural and manufactured gas underground and above-ground installations was determined. Although considerable information has been developed on the vulnerability of storage tanks for liquid petroleum products, no directly applicable vulnerability information is available for the large gas holders typical of municipal gas utility systems.

A study of the overall vulnerability of gas utility systems to nuclear attack was undertaken as a part of the Emergency Operations System Development (Refs. 10, 11 and 12). It considered the effects of blast on the various components of the gas utility systems in three cities but did not assess the probable repair effort that would be required. The Alaska earthquake caused some damage to the gas utility system in the Anchorage area, but the systems were back in operation within 48 hours (Ref. 5). SRI, in considering the effects of nuclear attack on the petroleum industry (Ref. 16), concluded that the gas transmission network extending from the wellhead to the city gate station was sufficiently isolated and dispersed (and relatively hard) so as to sustain little damage. A recent publication sponsored by the Department of the Interior provides guidance to the petroleum and gas industries on management procedures in case of nuclear attack but does not discuss damage or repair (Ref. 17).

Section 2

APPROACH

The approach used and the sequence are as follows:

Systems Description

Detailed functional descriptions of "typical" gas and electric utility systems were developed, with primary emphasis placed on the facilities located within the local or urban area (as contrasted with long-distance electrical transmission or gas pipeline networks). These functional descriptions included system components and encompassed supplies, repair parts, and maintenance materials. Personnel, however, were not considered to be components of the systems.

Critical Element Designation

The elements or components that are vital to the functioning of subsystems or systems were identified and rated as to criticallity, ie., the element's functional contribution to the system's operation. Key operational procedures were noted and materials and supplies which were essential to the continued operation of the system were indicated.

Damage Estimates

Damage to the various system elements (excluding personnel) was estimated for a wide range of weapon effects and intensities. Primary attention was directed toward overpressure, other weapon effects (heat, fire, ground shock, etc.) were considered in less detail, and the damage produced was incorporated into the overpressure damage estimates. All damage estimates are based upon a weapon in the 1-10 Mt range.* Fallout was not considered since it serves primarily as a constraint on personnel activity.**

---

* We considered a 5-Mt air burst as the weapon yield used for the analysis; however, the results are applicable to the 1- to 10-Mt yield range.

** The presence of fallout can impair the restoration of the system and can even contribute to the system's damage by necessitating rapid shutdown. Other studies (Ref. 6) have considered this aspect briefly.

Repair Estimates

Repair time and effort requirements were estimated for each critical element of the system individually and then summarized to obtain the repair reclamation "cost" for the utility. Repair effort was estimated in terms of repair time, required manpower (in terms of necessary skills and number), and the significant materials required. Repair estimates were prepared for all levels of damage with no regard to the probability of serving the relatively immediate needs of the population. Repair estimates were prepared for three levels of restoration and two classes of repair crew capability.

Development of a Repair Model

The results of the repair estimates were analyzed, and a mathematical model was developed to relate damage (as expressed in psi) to repair effort (in man-days or man-hours).

Repair of Total Utility Systems

A "typical" city with "typical" gas and electric utility systems was used to assess the repair requirements for various levels of damage.

Time-Phased Repair

The time-phasing of the repair effort was determined for each utility system, including requirements for manpower (by skill), supplies, and alternate operating procedures. Time-phasing, as used herein, refers to the necessary sequencing of the repair effort and not to an optimum scheduling such as would be attained with a CPM or PERT methodology. (These sophisticated techniques would certainly be applicable for postattack recovery efforts when actual values can be ascertained with some degree of confidence.)

REPORT ORGANIZATION

The basic analysis, which includes system description, designation of critical elements, damage assessment, and repair estimates, are described and briefly discussed in Section 3. The de led information generated for the repair of critical elements is tabulated in the Repair Analysis Sheets of

Appendix A. The derivation and use of the mathmatical repair model is described in Section 4, with Section 5 describing its application to a typical city. The time-phased repair for manpower and equipment is presented in Section 6. Discussion of the implications of the results of the repair study is made in Section 7, with conclusions and recommendations presented in Section 8. References constitute Section 9; a selected bibliography of utility operations is given in Appendix C. Supplementary repair information is listed in Appendix B.

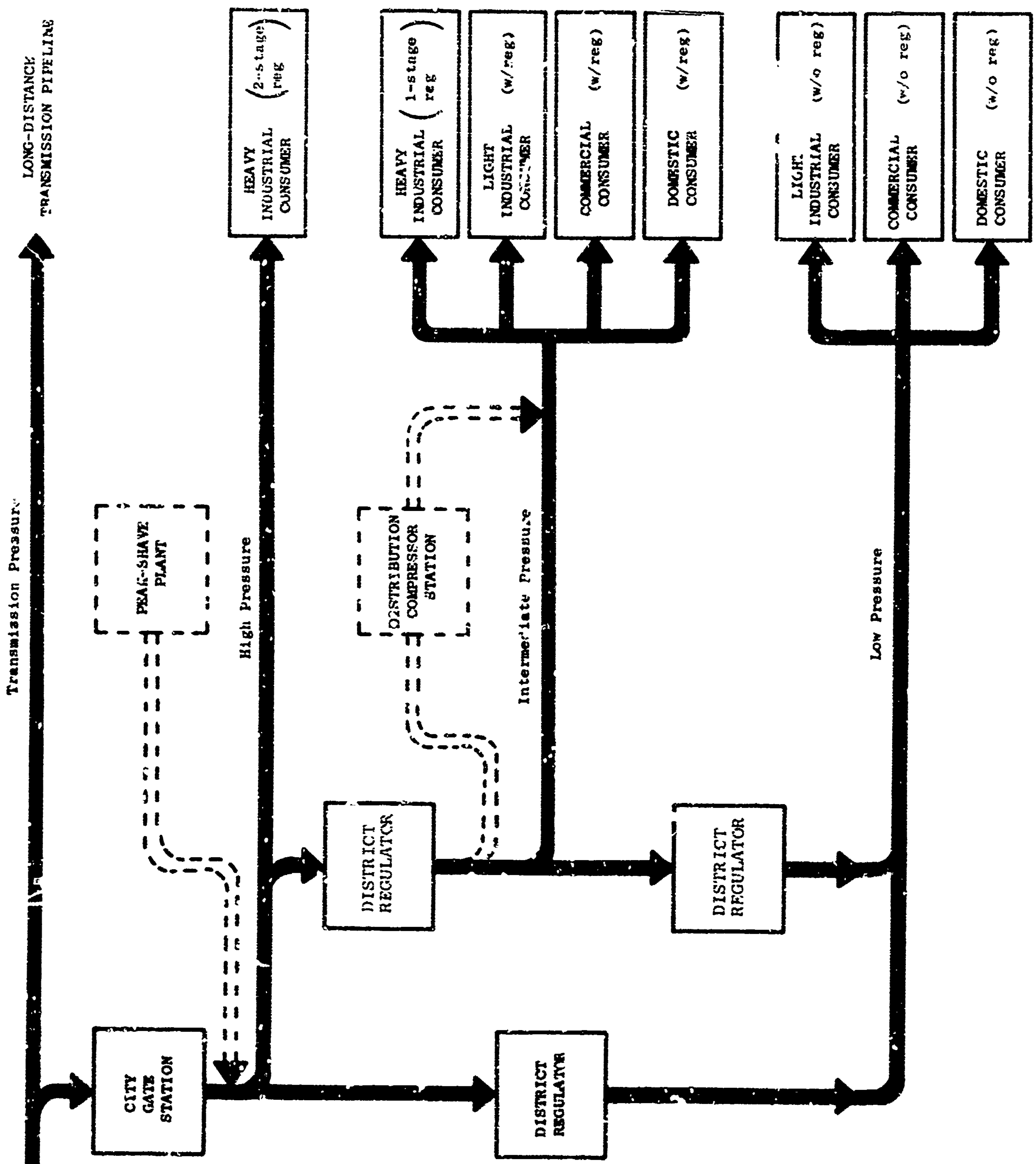
Section 3
BASIC ANALYSIS OF UTILITY SYSTEMS

This section includes the selection process used in describing typical gas and electric utility systems, the rationale for rating the criticality of components of the systems, the procedures for evaluating damage to the components, and the manner in which the repair estimates were made.

DESCRIPTION OF TYPICAL UTILITY SYSTEMS

As a first step in analyzing metropolitan gas and electric utility systems, the pertinent literature and statistics were surveyed (Refs. 1 – 19) to determine the general composition of such systems as they exist in this country. The spectrum found was broad and included differences in the service area, size, population, degree and type of industrialization, proximity to fuel sources and cooling water, climate, etc. Two "typical" utility systems were selected, one for gas, one for electric. These examples embodied the most common practices of existing systems throughout the country. This approach allowed our analytical efforts to be focused on specific items of equipment and specific design practices. Major subsystems within each utility system were then delineated and the number of individual elements comprising each of the subsystems quantified on the basis of the capacity of the major element of the subsystem (e.g., six feedwater heaters are required for the one boiler that was chosen for the boiler subsystem). Both current and out-of-date equipment, materials, and design practices were considered. Only facilities located in or near metropolitan areas were studied. For this reason gas wells, processing plants, transmission pipelines and compressor stations, hydroelectric and nuclear power plants, and long-distance transmission lines, all of which are normally remote to metropolitan area, were not considered in this study.

The "typical" systems actually studied are described briefly on the following pages and shown schematically in Fi s. 1 and 2. The rationale for selecting these generalized systems is also included.



SOURCE: Kennedy Engineers

Fig. 1. Overview - Gas Utility System

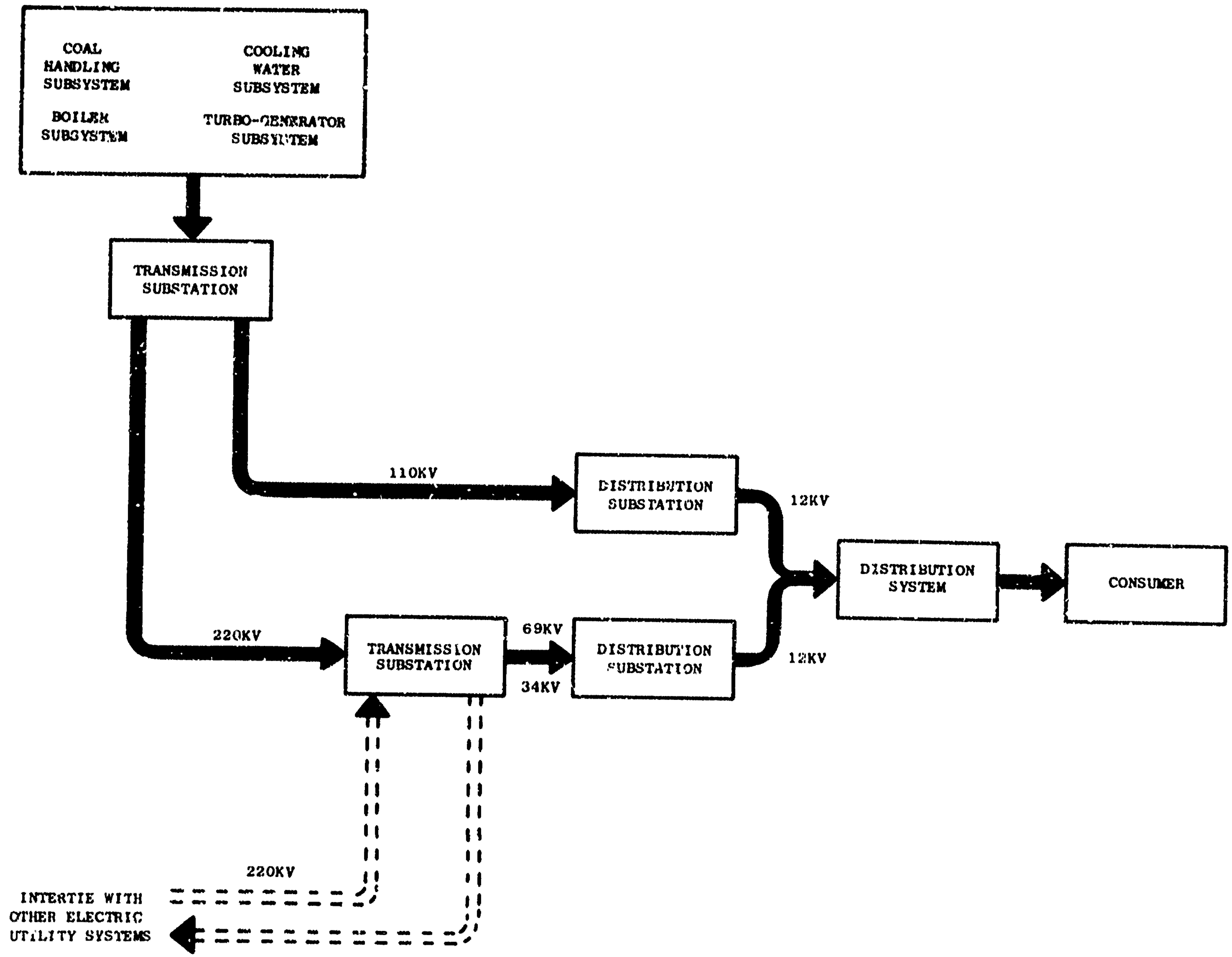


Fig. 2. Overview - Electric Utility System

SOURCE: Deamer/Wilkenson

Description of a Gas Utility System

The natural gas systems installed in this country can be divided, for purposes of discussion, into four basic segments:

- sources
- processing facilities
- long-distance transmission
- local distribution

Gas sources consist for the most part of gas wells, although petroleum refineries contribute to some extent. Processing facilities have the function of removing from the gas the various solid, liquid, and gaseous impurities which could interfere with the subsequent handling or use of the gas. Processing facilities are generally located relatively close to the source, and long-distance transmission systems transport the gas by pipeline from the processing facilities to the areas where the gas will be used. Major transmission pipelines are a foot or more in diameter and operate at pressures of several hundred pounds per square inch (psi). Because of the long distances involved (often many hundreds of miles), it is necessary to locate compressor stations along the pipelines to maintain high flow rates.

The local distribution system (the subject of this investigation) is shown schematically in Fig. 1. The city gate station serves as the interface between the distribution system and the transmission system by providing a means of drawing off gas from the high-pressure transmission pipeline. Besides reducing the pressure of the gas, the city gate station performs the important function of measuring and controlling the rate of flow into the distribution system. Additional functions often performed at the city gate station (depending upon the properties of the gas being handled, the nature of the distribution system, and the requirements imposed by the consumers) include:

- Adding special chemicals which impart a distinct odor to the gas, thereby making any leaks in the system readily dectectable.
- Filtering and cleaning the gas to remove fine solid or liquid impurities which could interfere with the operation of equipment in the distribution system and at the consumer's point of use.
- Oil fogging or humidification of the gas to protect pipes and pipe joints from deterioration (not universally practiced).

From the city gate station, the gas flows through the distribution system to the consumer. The distribution system itself consists primarily of gas mains of various sizes and materials. Older distribution systems consist of relatively large-diameter cast iron pipe operating at very low pressures (less than 1/3 psi). Such pipes are virtually inflexible and are therefore made up in short lengths connected with many bell-and-spigot type packed joints. Newer distribution mains are generally much smaller in diameter, operate at higher pressures, and are made of steel pipe with welded joints.

Gas pressures are high near the city gate station and lower near the consumer. Some of this pressure drop is due to frictional effects, but most is achieved by special installations called district regulators (shown in Fig. 1). District regulators consist of pressure-regulating valves which step the pressure down to specific predetermined levels, the degree of reduction depending upon the size, nature, and requirements of the system downstream. In some distribution systems, the pressure drop due to friction is excessive and must be compensated for by distribution compressor stations, which literally pump the gas through the mains.

Peak-shave facilities are often a part of the system. The term "peak-shave" is derived from and refers to the demand curve (a plot of flow rate vs. time). During periods of high gas use, the demand rises to maximums which often exceed the transmission system's capacity to deliver gas. The peak-shave plant is then employed as an in-system source of gas to "shave" off these "peaks" or maximums. The basic methods used for shaving peaks are: storage (either in-system storage achieved by temporarily boosting line pressures or off-system storage in high- or low-pressure holders) or substituting natural gas with manufactured gas (prepared by thermally breaking down coal) or with a blend of LP-gas* and air having properties similar to natural gas. The latter method is becoming more popular and has been examined in this study.

Service connections form the interface between the distribution system and the consumer and consist of a meter, a shutoff valve, and a service regulator (where the distribution pressure is too high for direct use by the consumer).

---

* LP-gas is an abbreviation for liquefied petroleum gas, a by-product of petroleum refining.

Informational sources which may be valuable to the reader who desires additional information on operational and technical aspects of the gas utility industry are listed in Appendix C.

Subsystem Description - Gas Utility

The subsystems on which the damage estimates and repair analyses were performed are described below. Any assumptions made concerning unit size, type, or location have been indicated where pertinent. Further information on each subsystem element is given on the Repair Analysis Sheets (Appendix A).

- City Gate Station - Major piping and appurtenances are mounted free-standing, aboveground, in a valve yard, with instrumentation and control system components located inside a prefab, steel industrial-type building. First-stage regulation is by compressed-air-operated regulator valves, lower pressure regulation and relief by gas-operated valves. Odorization facilities are of the injector type and are located in a small prefab steel shed separate from the main building.

- Peak-Shave Plant - Only the LP — air type plant was studied as the old manufactured-gas type is rapidly being phased-out of existing systems. All components of the plant (including piping) are located free-standing, aboveground, in a valve yard. Components are connected to form individual, independent modules, each module containing one 30,000-gal LP tank. While low-pressure aboveground gas holders are* used for peak shaving, they generally store only relatively small amounts of gas. Further, they are extremely vulnerable to weapon effects and would probably lose their stored gas at very low-overpressures. Once this occurs, the installations can provide virtually no postattack service (they cannot serve as a sole source of gas as can an LP-gas peak-shave plant) and their repair would not be feasible. Hence, they have been given no further consideration in this report.

- District Regulator Station - Components (a strainer, regulator valve, relif valve, and plug valves) are located belowground in a concrete vault covered by steel doors. Components are mounted directly on the gas pipe which passes through the vault.

* Their capacity is small compared with the total amount of gas demanded for a day's operation. Most cities could not operate under normal conditions for more than a day or so using only the gas stored in their low-pressure holders.

- Compressor Station - The station studied is of the type used for distribution pumping (i.e., maintaining pressure lost through pipe friction rather than the compression required for high- or low-pressure storage facilities). The system consists of an electrically driven reciprocating compressor located aboveground in a prefab, steel industrial-type building. A wood lath forced-draft-type cooling tower provides cooling for the compressor and the compressed gas.

- Domestic Service Installation - Meter (and regulator where applicable) is located outdoors just above ground level and directly adjacent to the building served. The service pipe rises from the ground, supports the meter, regulator, and shutoff valve, then enters the building.

- Commercial Service Installation - The meter (and regulator where applicable) is located outdoors at or just above ground level and directly adjacent to the building served. The service pipe rises from the ground, supports the meter, and then enters the building directly.

- Light Industrial Installation - The meter (and regulator where applicable) is located free-standing, aboveground, in a small, outdoor control complex.

- Heavy Industrial Installation - The meter and regulator (and first-stage regulation components) are located free-standing, aboveground, in a small outdoor control complex.

- Pressure Levels - The classifications used to identify operating pressures vary widely from system to system. For simplicity we have adopted the following:

Low Pressure -	3 to 12 in. W.C.*
Intermediate Pressure -	3 to 15 psi
High Pressure -	15 to 60 psi
Transmission Pressure -	several hundred psi

Description of an Electric Utility System

The electric utility system of a large metropolitan area, such as shown schematically in Fig. 2, usuallys consists of three major subsystems: generation, transmission and distribution.

A coal-fired, steam electric-generating plant, such as the one described in this study, would operate as follows: A rotary car dumper unloads coal from

* The abbreviation "W.C." refers to the manometric measurement of low gas pressures in inches of water column. (27 in. W.C. $\cong$ 1 psi).

freight trains onto conveyer belts which move the coal to hoppers and stockpiles and then, as needed, to coal pulverizers. The pulverized coal is mixed with heated air, supplied by forced-draft fans, and injected into the combustion chamber of the boiler. The boiler produces steam at very high temperatures and pressures (typically 1050°F and 2400 psi) which is fed to the impeller blades of the turbine, which, in turn, drives the generator through a direct connection. The spent steam is drawn by vacuum into the condenser (and condensed) and after treatment to remove impurities, pumped back to the boiler tubes via several reheat stages.

Auxiliary subsystems necessary to the operation of the turbine – generator set include: lubricating oil, hydrogen cooling, field excitation, and station bus. The lubricating subsystem circulates oil to the bearings of both the turbine and generator. Hydrogen is used in a closed system to cool the generator. The excitation subsystem provides DC power for the generator field, and the station bus provides the means of transmitting power to the auxiliary subsystems within the generating plant.

A typical transmission system in a metropolitan area usually consists of step-up transformer stations, transmission lines, switching stations, and step-down transformer stations of various sizes. A transmission line is considered here to include the conductors, insulators, and supporting towers. The basic elements of a transmission substation are: the transformer, which takes voltage at one level and either steps it up or down depending on its function; the circuit breaker, which protects the system by disconnecting it from the line when faults (i.e., short circuits) occur in the system; and the bus structure, which interconnects the circuit breaker, transformer, and transmission line.

A typical distribution system in a metropolitan area usually consists of primary distribution lines, distribution substations, and secondary distribution lines. The distribution substations are quite similar to the transmission substations (the elements are smaller, of course) and perform the function of reducing voltage from the transmission levels to the lower distribution levels. The distribution lines usually include wooden poles, conductors, insulators, and small, pole-mounted transformers, which reduce the voltage from the distribution level to household or commercial level. Industrial service is usually delivered at the primary voltage level.

Informational sources which may be valuable to the reader who desires additional information on operational and technical aspects of the electric utility industry are listed in Appendix C.

Subsystem Description - Electric Utility

The subsystem on which damage estimates and repair analyses were performed are described below. Any assumptions concerning unit size, type, or location have been included where pertinent. Further information on each subsystem element is given on the Repair Analysis Sheets (Appendix A).

- Coal Handling Subsystem - Consists of a pulverized coal system with a rotary car dumper and a covered coal conveying system. These are assumed to be located outside the generating plant building, with the coal pulverizers inside. Capacity is 120 tons/hour.

- Boiler Subsystem - The boiler is of the controlled forced-circulation type, is rated at 2,400,000 lb of steam at 2,700 psi, and contains an air heater, economizer, and superheating stages. Both the boiler and its ancillary equipment are located inside a large, reinforced concrete, steel-framed building. All ducts, flues, and piping are located inside the building, with forced-draft fans located outside next to the stack.

- Cooling Water Subsystem - Cooling is provided by a body of water (lake, river, ocean) rather than by cooling towers. The water intakes, traveling trash screens, and pumps are located at the water's edge in a light, concrete building. The condenser and hot-well pumps are located inside the generating plant building, under the turbine; reheaters are outside.

- Turbo-Generator Subsystem - The turbo-generator set is a 330-MW tandem compound, four-flow type with exciter, station bus, control cubicles, and 350-MVA generator transformer. All units except the transformer are located inside the generator building. A 30-psi hydrogen system provides cooling for the generator. Forced-feed lubrication of the turbo-generator set is provided by an oil pump.

- Transmission System - Free-standing 110-kV steel transmission towers are arranged in a network system. Substations are also included in this system and consist of four single-phase, step-down transformers (three in use and one standby) with four circuit breakers and appropriate bus structures (five disconnects per transformer).

- Distribution System - Free-standing wooden utility poles carry 12-kV lines*, with ten 50-kVA transformers per circuit mile of distribution.

* One 12-kV circuit consists of three bare conductors; insulated conductors are commonly used only in underground service or in low voltage and service connections to consumers.

CRITICAL ELEMENTS

One of the goals of this study was to determine the relative importance of each utility system component in terms of its contribution to the functioning of the system. This effort is germane to the realistic evaluation of subsequent repair requirements, both in terms of the amount of repair effort involved and the scheduling of these repairs. With such information, it is possible to avoid repairing any components that do not contribute significantly to the system's principal postattack function (i.e., that of providing gas or electricity). Accordingly, the functional contribution of each element was carefully examined, then its "criticality" was rated in terms of the following classifications:

CRITICAL (C) — Loss of element would result in a loss of <u>more</u> than 10-percent of the design capacity. The cause of this reduction in capacity might be due to operational limitations or a degradation of the system's safety or reliability.

SEMI-CRITICAL (SC) — Operation without element would result in a loss of <u>less</u> than 10 percent of design capacity. The safety or reliability of the system might be degraded somewhat, but not seriously. Conversion of the system to operate without this element would <u>require</u> a significant expenditure of manpower and/or materials.

NON-CRITICAL (NC) — Operation without element, would result in a loss of <u>less</u> than 10 percent of design capacity. The safety or reliability of the system might be degraded somewhat, but not seriously. Conversion of the system to operate without this element would <u>not require</u> any significant expenditure of manpower and/or materials.

These ratings are used in Figs. 3 and 4. Those elements rated as "non-critical" are identified as such but receive no further consideration in this report.

DAMAGE ESTIMATES

Critical and semi-critical elements of the utility systems were examined to determine the extent and nature of damage they would receive as a result of nuclear attack. The purpose of these damage estimates was to establish a quantitative relationship between given levels of damage and the overpressure at which such damage would occur. This information was subsequently combined with information relating damage to the repair effort required for restoration, the result being a relationship between overpressure and repair requirements.

SUBSYSTEM	CRITICAL ELEMENT	CRITICALITY RATING	REF TO APPENDIX A	NUMBER IN SUBSYSTEM (N)
City-Gate Station	First-stage pressure regulators	C	G-1a	2
	Compressed air supply system	C	G-1b	1
	Second stage pressure regulators	C	G-2	2
	Orifice-type flow meters	C	G-3	2
	Odorization facility	C	G-4	1
	Control and dispatching facilities	NC	G-5	
	First-stage pressure relief valves	SC	G-6	2
	Second-stage pressure relief valves	SC	G-7	2
	Office, dispatch, and control building	SC	G-8	1
	Gas filtering and cleaning facilities	NC	G-9	
	Oil fogging facilities	NC	G-10	
	Humidification facilities	NC	G-11	
District Regulator Station	Strainer	SC	G-15	1
	Pressure regulator	C	G-16	1
	Pressure relief valve	SC	G-17	1
Peak Shave Plant	LP-gas storage tanks	C	G-12a	2
	Vaporizer-mixer units	C	G-12b	2
	Surge tank	C	G-12c	
Distribution Compressor Station	Compressor-prime mover assemblies	C	G-18a	3
	Major piping and valving system	C	G-18b	1
	Electrical control systems	C	G-18c	3
	Cooling tower	C	G-18d	1
	Prefab steel building	SC	G-18e	1
Domestic Service (w/ reg)	Service regulator	C	G-13a	1
	Service meter	SC	G-14a	1
Domestic Service (w/o reg)	Service meter	SC	G-14a	1
Commercial Service (w/ reg)	Service regulator	C	G-13a	1
	Service meter	SC	G-14b	1
Commercial Service (w/o reg)	Service meter	SC	G-14b	1
Light Industrial Service (w/ reg)	Service regulator	C	G-13b	1
	Service meter	SC	G-14c	1
Light Industrial Service (w/o reg)	Service meter	SC	G-14c	1
Heavy Industrial Service (two-stage reg)	Service regulator	C	G-13b	1
	Service meter	SC	G-14d	1
	Strainer	SC	G-15	1
	Pressure regulator	C	G-16	1
	Pressure relief valve	SC	G-17	1
Heavy Industrial Service (single-stage reg)	Service regulator	C	G-13b	1
	Service meter	SC	G-14d	1

SOURCE: Kennedy Engineers

Fig. 3. Typical Gas Utility System Elements

SUBSYSTEM	CRITICAL ELEMENT	CRITI-CALITY RATING	REF TO APPENDIX A	NUMBER IN SUB-SYSTEM (N)
Coal Handling	Coal conveyor systems	C	E-1	1
	Rotary car dumps	SC	E-1	1
	Coal pulverizers	C	E-2	8
Boiler	Air heaters	SC	E-3a	2
	Soot blowers	SC	E-3a	50
	Dust collectors	SC	E-3b	2
	Hot air ducts and flues	C	E-3b	1
	Boiler	C	E-4	1
	Forced-draft fans	C	E-5	2
	Feedwater pumps	C	E-7	2
	Deaerator	SC	E-7	1
	Feedwater heaters	C	E-7	6
Cooling Water	Cooling water intake	C	E-6a	1
	Condenser	C	E-6a	1
	Hot-well pumps	C	E-6b	2
Turbogenerator	Turbogenerator assembly	C	E-8	1
	Lubricating oil system	C	E-8	1
	Hydrogen cooling system	C	E-8	1
	Exciter unit	C	E-9	1
	Station auxiliary bus	C	E-9	1
	Metering, protection, and control modules	C	E-10	45
Transmission Substation	Bus structure	SC	E-11	1
	Circuit breaker	SC	E-11	1
	Transmission transformer	C	E-12a	1
	Control system	NC	E-12c	1
	Transmission line and towers	C	E-13	
Distribution Substation	Bus structure	SC	E-11	1
	Circuit breaker	SC	E-11	1
	Distribution substation transformer	C	E-12b	1
Distribution	Distribution line	C	E-14	
	Power poles	C	E-14	
	Transformers (pole mounted)	C	E-14	10/mile
	Service drops	SC	E-14	200/mile

SOURCE: Beamer/Wilkinson

Fig. 4. Typical Electric Utility System Elements

Approach

The damage to specific utility elements was estimated using the following approach:

- Delineation of the specific design characteristics and function of each element, and establishment of the general installation practices for each element.
- Relating the failure mode predictions for each element to several levels of damage (i.e., light, medium and heavy),* using past research (Refs. 1 - 4, 14 - 16, 18 and 19), calculations, and engineering judgement.
- Relating all weapon effects to the corresponding overpressure levels (i.e., the diffraction phase of the blast wave).

The damage estimates prepared in this study were directed toward specific pieces of equipment that we considered to be typical of actual installed systems. Similar (and even functionally equivalent) equipment supplied by a different manufacturer or made from a different material might react in a different manner when subjected to the same weapon effects, but the overall effect on the repair estimates would not be significant.

Two other factors affect the severity of damage at any given overpressure level: the directional orientation of the element to the blast wave front and the proximity of the element to other components or structures. Elements of the electric distribution systems are particularly sensitive to directional orientation. Lines and poles oriented parallel to the blast wave front are considerably more vulnerable than those oriented toward the detonation. Since the actual direction of installed lines varies widely even within a single system and the relative direction varies markedly with changes in the location of ground zero, this study assumed a random orientation of electric distribution poles.

The proximity of elements to other components or structures affects the severity of damage resulting from both missiles and reflected overpressure. Fo.

---

* Damage was assumed to be produced by a 5-Mt low air burst with all overpressures in the Mach region. Although a rigorous analysis of other weapon yields was not pursued the results of the damage estimations should be applicable for weapon yields in the low megaton range (0.5 — 10 Mt).

this reason, each element's assumed location (with respect to being aboveground or belowground or indoors or outdoors, but not with respect to other items of equipment) is stated in the Repair Analysis Sheets. The significance of missile damage is discussed below. Reflected overpressure, on the other hand, was not examined in detail due to a lack of specific information regarding equipment location relative to possible blast-reflecting surfaces.

Results

Description of the damage for each critical and semicritical element is given in the left hand column of the Repair Estimate Sheets (Appendix A). Four weapon effects, overpressure, dynamic pressure, missiles, and thermal pulse, were considered as contributing to damage; the findings for these four effects are, in brief, as follows:

Overpressure was found to be a major cause of damage only to buildings; however, in some instances it was a contributory cause of damage to aboveground elements.

Dynamic pressure was found to be a major cause of damage to exposed aboveground elements. Since the duration of drag loading from the 1- to 10-Mt weapon yield range used in this study exceeds the natural vibration period of any of the drag-sensitive elements, the elements' failure mode was analyzed by means of a static loading scheme.

Missiles, caused by the effects of overpressure and dynamic pressure on otherwise stationary objects, were found to contribute significantly to the damage of nearly all aboveground utility system elements. Those elements located inside buildings or in relatively built-up areas were damaged primarily by missiles generated by overpressure effects. Elements located outdoors in less built-up areas received damage from missiles propelled by the drag effects of the dynamic pressure.

Thermal pulse was found to cause varying but relatively insignificant damage to the major elements of the gas and electric utility systems. Aside from possible changes in the dielectric properties of transformer oil, most thermal effects were limited to ancillary components (such as the weakening of copper tubing used for instrumentation and control). The most significant effect of the thermal pulse was its initiation of primary ignitions and its contribution to secondary fires, the effects of which could not be covered in detail in this study.

Three weapon effects, electromagnetic pulse (EMP), direct-induced ground shock, and air-induced ground shock, were not considered with respect to their effects on individual critical elements, but the implication of these effects on various utility subsystems was briefly considered. The results of this cursory examination are listed below:

Electromagnetic pulse is considered to be a possible detrimental factor and may damage the electric distribution system due to flashover and short-circuiting which result from the voltages induced in conductors as the pulse front moves past the conductors. The simultaneous disruption of power and control circuitry in the electrical generating system might lead to severe but unpredictable damage to generators, turbines, transformers, circuit-breakers, etc. Although a detailed analysis of these effects was beyond the scope of this study, we suggest that further research might well be directed toward establishing and evaluating the physical effects of the electromagnetic pulse on electric utility systems.

Direct-induced ground shock can cause damage to underground lines and components of both gas and electric utility systems, the degree of damage falling off rapidly with distance from ground zero. It is expected that underground components will receive significant damage only within the zone of plastic soil movement. Since this zone is relatively small and would simultaneously be subjected to extremely high overpressure and thermal levels, the direct-induced ground shock is felt to be of minor significance. However, it is conceivable that at greater distances ground shock could trip certain safety devices installed in utility systems for the purpose of limiting damage from earthquakes. However, additional research is necessary to establish the extent of the problems likely to be created by direct-induced ground shock.

Air-induced ground shock is expected to cause virtually no damage to underground gas and electric utility installations at surface overpressure levels below 10 or 15 psi. Above this level, damage is expected to occur, its severity increasing with overpressure. However, after review of the pertinent literature and consultation with a leading soil dynamicist (Ref. 20), it has been concluded that the present state of the art is not sufficiently advanced to allow even approximate quantitative prediction of what damage would result from given overpressure levels. Several factors combine to render such predictions impossible at present:

- The structural properties of the pipe itself are unknown and cannot be predicted on a generalized basis. The fact that pipe which has been installed for a long period of time is subject to various effects* which significantly alter its material properties precludes any structural analyses based upon the bending of a homogeneous, elastic member.
- The manner in which the pipe is supported is unknown and cannot be predicted. The soil surrounding and underlying the pipe is far from homogeneous, it may contain large inclusions, and its moisture content may vary widely. The type and number of joints in the pipe affect the support pattern, as does the termination of the pipe at a building or manhole or buried valve.

---

* Corrosion, erosion, crystalization, carbonization, etc.

- The actual loading on the pipe cannot be predicted in a generalized manner since it depends heavily upon numerous specialized local considerations (the dynamic response characteristics of the soil, the depth of burial, the orientation of the pipe relative to the direction of the blast wave front, whether the pipe is located beneath pavement, etc.).

These and numerous other factors prevent us from predicting in what mode a given pipe will fail. To predict at what overpressure failure would occur is even more remote at the present state of the art.

REPAIR ANALYSIS

Approach

The repair effort required to restore a given component of the damaged system depends heavily upon the qualification of the repair crew and the degree of restoration (expressed in terms of the level of system performance required after repair).

Recognizing that the postattack supply of skilled manpower may be rather limited, we have considered two levels of qualification for repair crews:

I. All repairs would be performed by skilled repair personnel using the equipment, supplied, and facilities normally available under preattack conditions.

II. Repairs would be performed by crews made up of semi-skilled personnel. Workers skilled in utility repair or similar trades would serve in a supervisory capacity wherever possible.

Recognizing that different elements in the same system need not necessarily be repaired to the same level of completeness to perform properly, we have considered three degrees of restoration for each element:

A. The repaired system would be virtually identical to the original (preattack) system from the standpoints of design, performance capabilities, operational requirements, relisbility, safety, and longevity.

B. The repaired system would provide at least 90 percent of the preattack design performance, but might not incorporate the same design, require the same operational inputs (manpower, energy, or materials), or provide the same longevity.

C. The repaired system would be an expedient, directed toward providing a maximum level of performance per unit repair effort expended. Output would generally be at least 30 percent of design capacity. System efficiency, ease of maintenance and operation, reliability, and safety may be significantly degraded.

Repair estimates for each combination of repair crew qualification (i.e., I and II) and each level of repair completeness (i.e., A, B, and C) were prepared. The following basic assumptions were made (more specific information appears in the Repair Analysis Sheets in Appendix A):

- No unusual environmental conditions* are present to interfere with the repairs.
- Spare parts, materials, equipment, and special facilities are available immediately unless noted otherwise.
- Travel times to, from, and between repair sites are not included.
- Time has been allowed for the field testing of each repaired element but not for testing the entire system following repair.
- The values given for repair effort do not include the time spent by supervisory personnel above the level of "foreman."

The limitations associated with the repair estimates are related to three factors: specific equipment, equipment location, and manpower. The repair estimates have been based on specific equipment that was judged typical; however, equipment of different size or equipment made by other manufacturers could require a somewhat different repair effort. The location of specific utility elements relative to other elements in a system is a factor because travel time to and from the job sites (or between elements) to accomplish repair was not considered in the overall repair estimates. This analysis looked at two levels of labor skills to perform the estimated repair: work performed completely by skilled labor and work performed mainly by semi-skilled labor with some skilled supervision. This latter category usually required two to three times the effort to repair an element as did the skilled labor group,

---

* Inclement weather, frozen soil, flooding, high groundwater table, fallout radiation, fires, or remote or inaccessible location.

where a low level of repair effort is indicated, this factor would probably be accurate if not on the conservative side; however, with jobs that might last upwards of 200 to 300 days, it is realized that the semi-skilled labor would gradually become skilled in the particular jobs they were performing and would thereby increase their repair rate considerably. Because this learning factor is difficult to estimate, it has been ignored in this analysis. One final factor affecting the repair estimates, is that repair effort has been based on predicted damage to an element; therefore, any factor that would change the damage estimates would consequently influence a change in the repair estimates.

Results

The results of the repair analyses appear in tabular form in the Repair Analysis Sheets in Appendix A. Both damage and repair estimates are keyed to overpressure, with other weapon effects cited specifically as they apply.

Generally, the repair effort required to restore the system is highest for the "A" mode and lowest for the "C" mode (as would be expected). In several cases, however, the "B" mode requires more effort than "A." This occurs where it was assumed for the "A" mode that the damaged element was replaced by a new, factory-built element, whereas "B" involved repairing the damaged element or even fabricating a substitute for it.

It should be noted that there is an inverse relationship between the need for skilled labor and the need for special repair parts. In cases where common repair parts are unavailable or in short supply, the actual repair techniques employed might require a higher degree of skill from the workers. For example, leaking pipes could be repaired by bolting special rubber-lined flanged clamps over the breaks, a task easily performed by any worker having only minimal skills. In the absence of such special clamps, only a skilled welder* would be able to repair the break. This sort of inverse relationship applies in varying degree to both the gas and the electric utilities. Aside from being recognized and cited here, it was given no further consideration in this report due to its complex nature.

* i.e., a welder familar with both welding techniques and their use in the face of escaping gas.

The assumption that spare parts, materials, and equipment will be available as needed in the disrupted postattack period raises certain difficulties. Even under peacetime conditions, many items have procurement lead times of 6 weeks to 24 months (Ref. 21). The reasons for such delays are numerous but are generally related to the fact that the balance between supply and demand is difficult to achieve.* In certain industries, this has led to a high degree of specialization and dependence upon a few suppliers. During the postattack period, the demand for many items would be staggering. The ability to meet the demand might well be hopelessly hampered by the reduced availability of raw materials, personnel, power, and the disruption of both communications and transportation. Although we have recognized the effect this reduced availability of resources has on the validity of this utility repair study, we are only able to cite it, since its quantification is clearly beyond the scope of the study. The particular portion of the study most seriously affected would be the repair schedule (Section 6).

The use of communications is extremely important in controlling operations between various facilities within relatively large, metropolitan gas or electric utility systems.** The loss of an effective communications system would impose a severe constraint on a utility's ability to restore operations. Although it was beyond the scope of this study to quantitatively define the extent of a communications constraint (an SRI report - Ref. 23, discusses the role of communications in civil defense), some general effects can be qualitatively delineated for each utility.

- Gas utility - If gas storage and peak-shave facilities are lost, communications are vital in dispatching gas. Without communications to regulate transmission gas flow, it would be extremely difficult to provide steady pressures and flow rates throughout a relatively large system. In a small system, communications are not generally as important.

---

* Demand does tend to regulate the supply, but a long lead time is required for large items because they are normally not designed, much less manufactured, until ordered. Following nuclear attack, when massive repair efforts would be required, it is probable that available manufacturing capacity (even by preattack standards) could provide only a small fraction of the required long-lead-time supplies.

** Distribution and dispatching centers maybe tied together by any combination of the following utility owned independent communications systems: leased telephone wire, utility-owned telephone, microwave transmitters, and utility-owned two-way radios (many of which are limited to units in mobile repair vehicles). In addition, many electric utilities can transmit voice messages over power lines.

- Electric utilities - Communications are used in the electrical system to regulate variable load conditions. Without communications, dispatching centers would be hard pressed to shift the load where required. Also, re-establishing interties would be extremely difficult.

Section 4
DEVELOPMENT OF A REPAIR MODEL

The output of the basic utility analysis produced many data relating damage to repair effort required. These data (presented in Appendix A), although useful for specific components, are in a somewhat awkward form for use for analyzing systems or subsystems. Therefore, a means of expressing these data in a form more convenient and easier to handle was sought and led to the development of a mathematical model which relates weapon effects (expressed in terms of overpressure level) to the subsequent repair effort. The mathematical model also serves another purpose, viz., the smoothing out of irregularities in the data, thereby providing more consistent repair estimates.

A preliminary analysis of the repair estimates indicated that the relationship between <u>repair effort</u> and <u>overpressure</u>* could best be expressed as an exponential function. After consultation with Dr. Alan McMasters (Ref. 22) an expression for repair effort as a function of overpressure level was derived:

$$R = L\left[1-e^{-K(p-X)}\right]$$

where:

R = repair effort (man-days)

L = maximum repair effort (man-days)

p = overpressure (psi)

X = lowest overpressure at which damage occurs (psi)

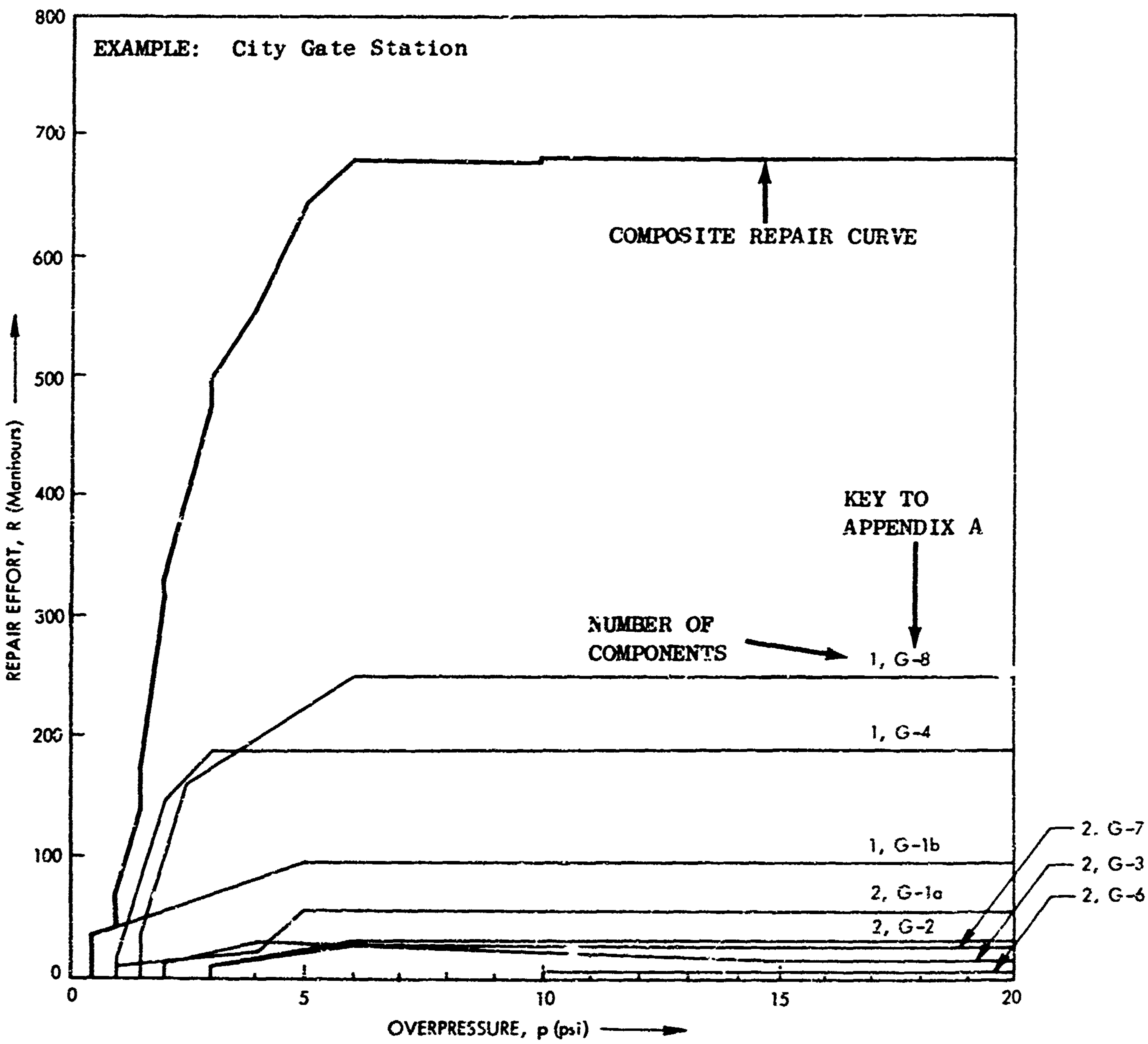
K = empirical constant for a given subsystem

---

* As mentioned in Section 3, all weapon effects considered (overpressure, dynamic pressure, missiles and thermal pulse) have been related to one effect: overpressure. Hence, even though overpressure is the index used, all effects which contribute to damage to a given component are implicit in this index.

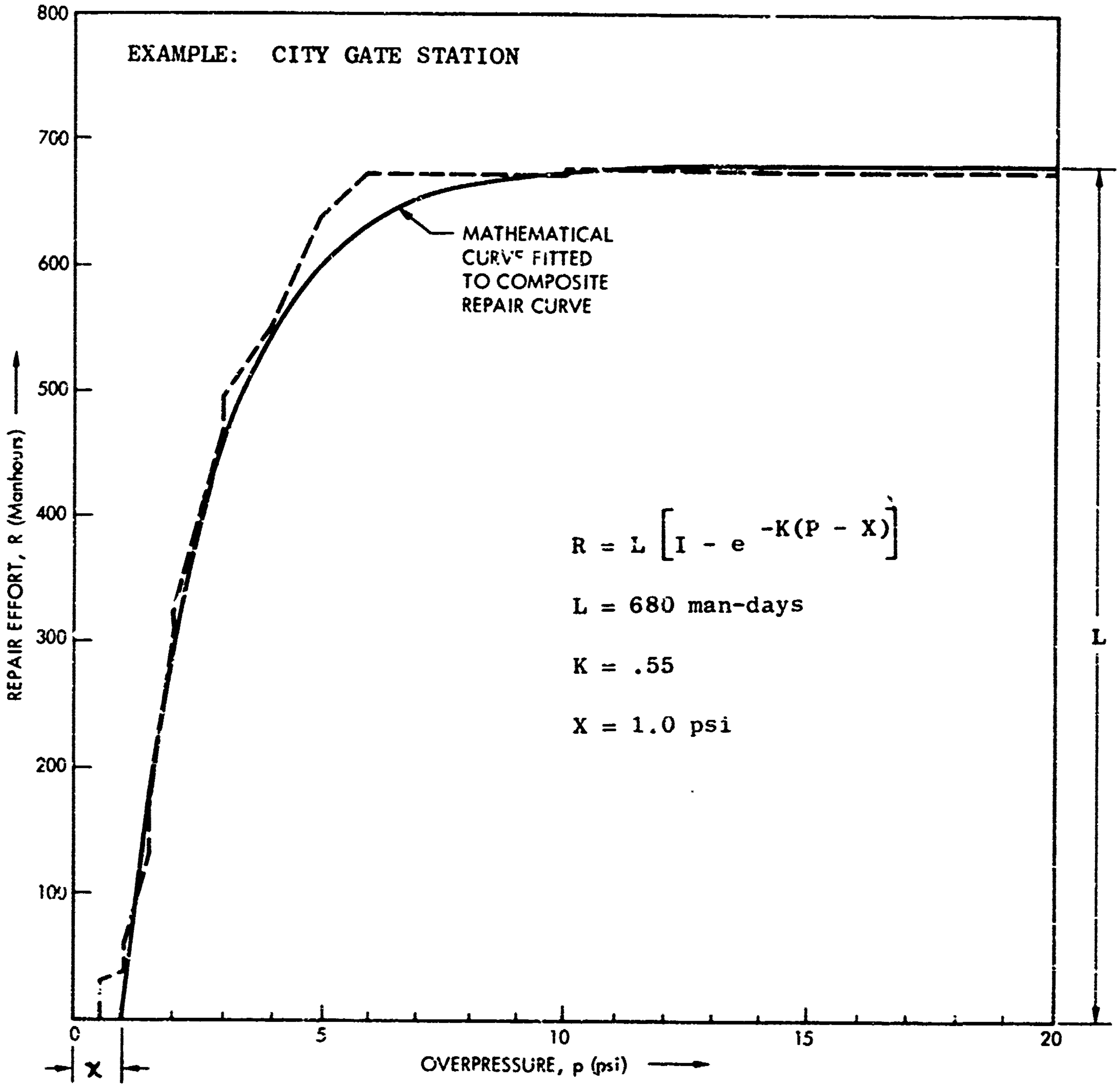
The equation is applicable to individual components, but since the goal of the model was to reduce the number and complexity of the repair analysis, attention was directed to subsystems. Accordingly, repair estimates were prepared for each subsystem, as defined in Figs. 3 and 4, using the number of components (N) listed. Results for the gas utility's city-gate station (from data in Tables G-1a through G-8, in Appendix A) are shown in Fig. 5. The repair curves (prepared by drawing straight lines between each data point) are shown as fine lines, and the composite curve, i.e., the gas compressor subsystem, resulting from the addition of the repair effort for the components comprising the subsystem, is shown as the heavy line. The manner in which the equation "fits" the composite curve is shown in Fig. 6. This fit, which is typical of most cases, is remarkably good. Deviations of the model from the data do occur, particularly at the lower end of the curve, but considering the overall reliability of the data themselves, the model is considered to be a generally acceptable expression for repair effort.

A similar procedure was used to develop curves for each of the subsystems in the gas and electric utilities. Rather than reproducing a number of such curves, we have listed the controlling parameters, L, K, and X, in Tables 1 and 2 for three repair modes and two types of labor force (as discussed in Section 3). It was found that only L varied for each individual case considered, with K and X remaining constant for a given subsystem.



SOURCE: URS Corporation

Fig. 5. Derivation of a Composite Repair Curve



SOURCE: URS Corporation

Fig. 6. Mathematical Curve Fitted to Composite Repair Curve

Table 1

MATHEMATICAL MODEL: GAS UTILITY SYSTEM

$$R = L\left[1 - e^{-K(p - X)}\right]$$

R = Repair effort (man-hr)

p = Overpressure (psi)

SUBSYSTEM	L (man-hr) IA	IB	IC	IIB	IIC	
CITY GATE	680	680	500	1200	950	K = .55, X = 1
DISTRICT REGULATOR	31	32	33	62	59	K = .90, X = 2.75
PEAK SHAVE	180	220	140	310	340	K = .50, X = 1 (drops to R = 0 at P = 5)
DISTRIBUTION COMPRESSOR STATION	5000	4600	3900	7400	6600	K = .11, X = 1
DOMESTIC SERVICE (w/ reg)	2.0	2.0	2.0	3.5	3.75	K = 2, X = 4
DOMESTIC SERVICE (w/o reg)	1.0	1.0	1.0	1.75	2.0	K = 2, X = 4
COMMERCIAL SERVICE (w/ reg)	13	13	5.0	22	8.0	K = 2, X = 4
COMMERCIAL SERVICE (w/o reg)	12	12	4.0	20	6.0	K = 2, X = 4
LIGHT IND SERVICE (w/ reg)	28	28	24	52	48	K = .70, X = 6
LIGHT IND SERVICE (w/o reg)	12	12	8.0	22	16	K = 2, X = 7
HEAVY IND SERVICE (single-stage reg)	32	32	23	62	44	K = .50, X = 3
HEAVY IND SERVICE (two-stage reg)	64	64	58	124	108	K = .50, X = 2.5

SOURCE: URS Corporation

Table 2

MATHEMATICAL MODEL: ELECTRIC SYSTEM

$$R = L\left[1 - e^{-K(p - X)}\right]$$

R = Repair effort (man-days)

p = Overpressure (psi)

SUBSYSTEM	L (man-days)					
	IA	IB	IC	IIB	IIC	
COAL HANDLING	2600	1500	1200	3400	2500	$\begin{cases} K = .2 \\ X = 4 \end{cases}$
BOILER	59000	55000	47000	140,000	110,000	$\begin{cases} K = .12 \\ X = 4.5 \end{cases}$
COOLING WATER	2300	1800	1400	4150	3400	$\begin{cases} K = .4 \\ X = 3.5 \end{cases}$
TURBO-GENERATOR	4100	2600	1660	6600	3750	$\begin{cases} K = .3 \\ X = 2.5 \end{cases}$
TRANSMISSION* SUBSTATION	920	430	142	1120	415	$\begin{cases} K = .50 \\ X = 5 \end{cases}$
DISTRIBUTION*	200	180	180	220	220	$\begin{cases} K = 1.0 \\ X = 2.3 \end{cases}$

* In man-days/mile

SOURCE: URS Corporation

Section 5
REPAIR EFFORT FOR A TYPICAL CITY

The repair model described in Section 4 provides a means of predicting repair requirements on a subsystem-by-subsystem basis. However, to ascertain the true impact of a nuclear attack on a utility, it would be necessary to analyze an entire utility system. This approach would reveal the interdependency of the various subsystems and their relative importance. A real utility system in a real city would have been used for this analysis had sufficient data been available. However, since this was not the case, a hypothetical or "typical" city with "typical" utility systems was synthesized. This approach has the additional advantage of avoiding many of the atypical characteristics found in any real city. Using available information on municipalities and "rules of thumb," typical utility systems were constructed (in terms of how many of each type of subsystem is present) for the typical city. The model was then used to determine what repair effort would be required to restore service.

The typical city used for analysis is assumed to have a population of 400,000 and cover an area of 100 square miles. Characteristics of the gas and electric utility systems serving the typical city are described in Tables 3 and 4 respectively.

APPROACH

The repair analysis of the typical city's gas and electric utilities drew upon the mathematical model prepared earlier for the various subsystems (Tables 1 and 2). Repair effort values corresponding to various overpressure levels were calculated, multiplied by the appropriate number of subsystems involved, and summed to give the total repair effort required at that overpressure. The I-B repair mode, i.e., skilled workers restore the damaged system to just short of its initial capacity, was selected for this analysis, even though it was recognized that the choice was optimistic. That is, in many cases skilled manpower would be in short supply and in other cases restoration to only an expedient level would suffice. The skilled labor category (mode I) was chosen

Table 3

TYPICAL CITY GAS UTILITY

10-city gate stations (or equivalent)

150-district regulator stations

6-peak shave plants (LP-air; 50,000 cfh capacity each)

1600-circuit miles of distribution and service mains:

Distribution mains:	2" to 8" for 60 to 150 psig
Service mains:	2" to 8" for 5 to 60 psig
	and
	8" to 24" for 8 in. w.c.

140,000-domestic services (98,000 w/o regulation)

10,200-commercial services (7,000 w/o regulation)

650-light industrial services (340 w/o regulation)

115-heavy industrial services (100 single-stage regulation only)

Average Demand:

5 million cfh (summer)

10 million cfh (winter)

SOURCE: Kennedy Engineers

Table 4

TYPICAL CITY ELECTRICAL UTILITY

1-steam generating station (two 300 MW turbo-generators and appropriately sized ancillary equipment)

1-switchyard substation (located adjacent to generating station)

980-circuit miles of 12 kV distribution system

- 160,000 residential services
- 13,000 commercial services
- 1,000 light industrial services
- 120 heavy industrial services

80-circuit miles of transmission line (ring plus partial network)

- 40 miles - 110 kV
- 20 miles - 69 kV
- 20 miles - 34 kV

28-substations (with 4 single-phase transformers each)

- 8 - 110 kV to 12 kV
- 10 - 69 kV to 12 kV
- 10 - 34 kV to 12 kV

SOURCE: Beamer/Wilkinson

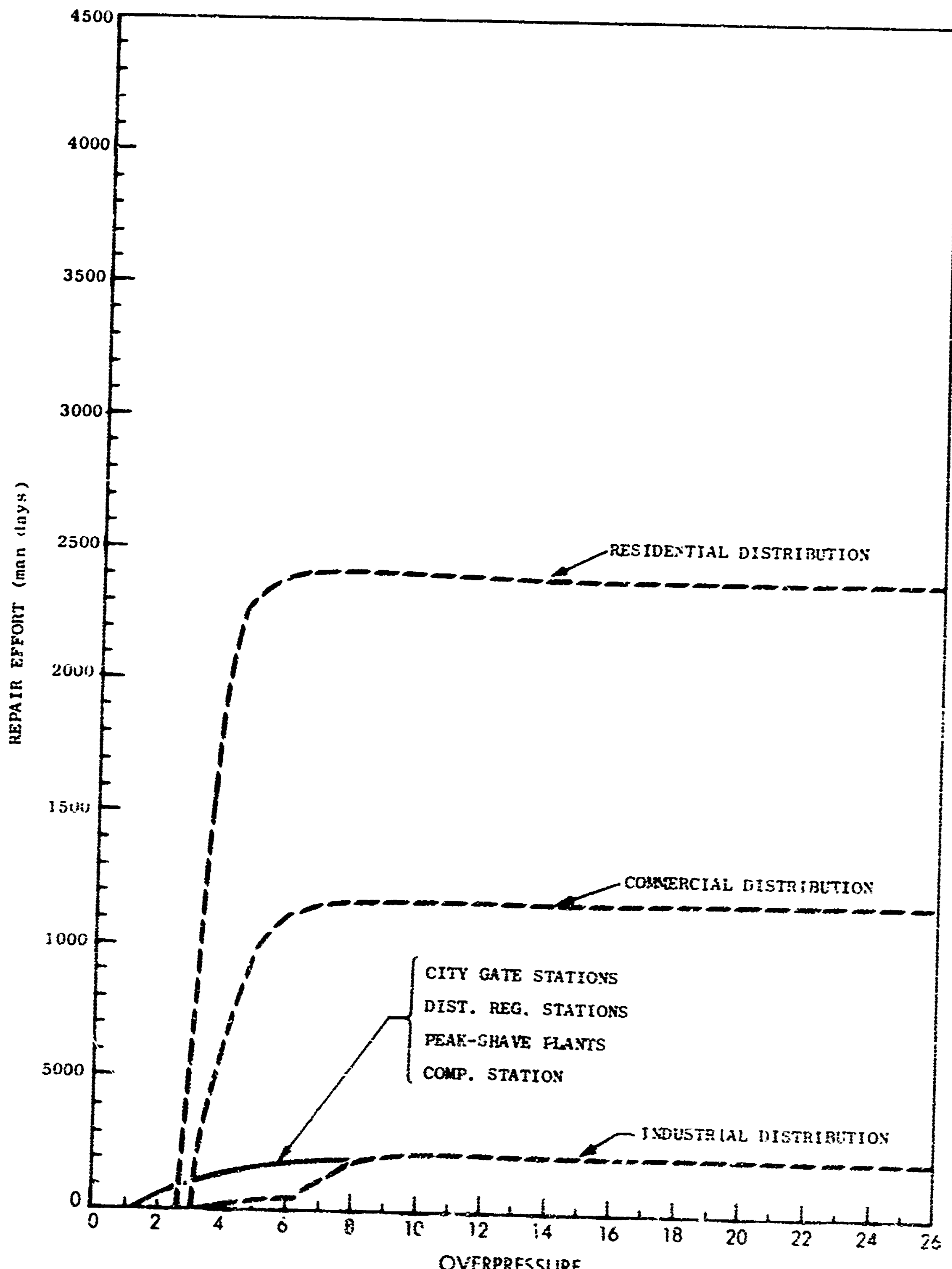
in preference to alternate labor category (mode II) because working times are more predictable when using known skills. Repairing a utility system to the "A" level (preattack design and capacity) was regarded as being rather academic due to probable resource shortages and time constraints, while repairing the system to the "C" level was rejected because it causes major degradation to system operations and would probably only be used on some elements on a temporary basis.*

A parametric approach was used to test the effects of various damage levels on the typical city. In this parametric study it was assumed that all subsystems comprising the utility system within the typical city were subjected to the same overpressure, e.g., the generating, transmission and distribution subsystems would all experience a simultaneous overpressure of 4 psi. A number of overpressure levels encompassing the range from 1 to 25 psi were examined in this fashion. The parametric approach (rather than an approach using a specific weapon at a specific location) permits easier comparison of the relative "hardness" of each subsystem and clarifies the interrelationship between subsystems. The results could, with some additional manipulation, be used to prepare repair estimates for other situations, either real or simulated.

RESULTS

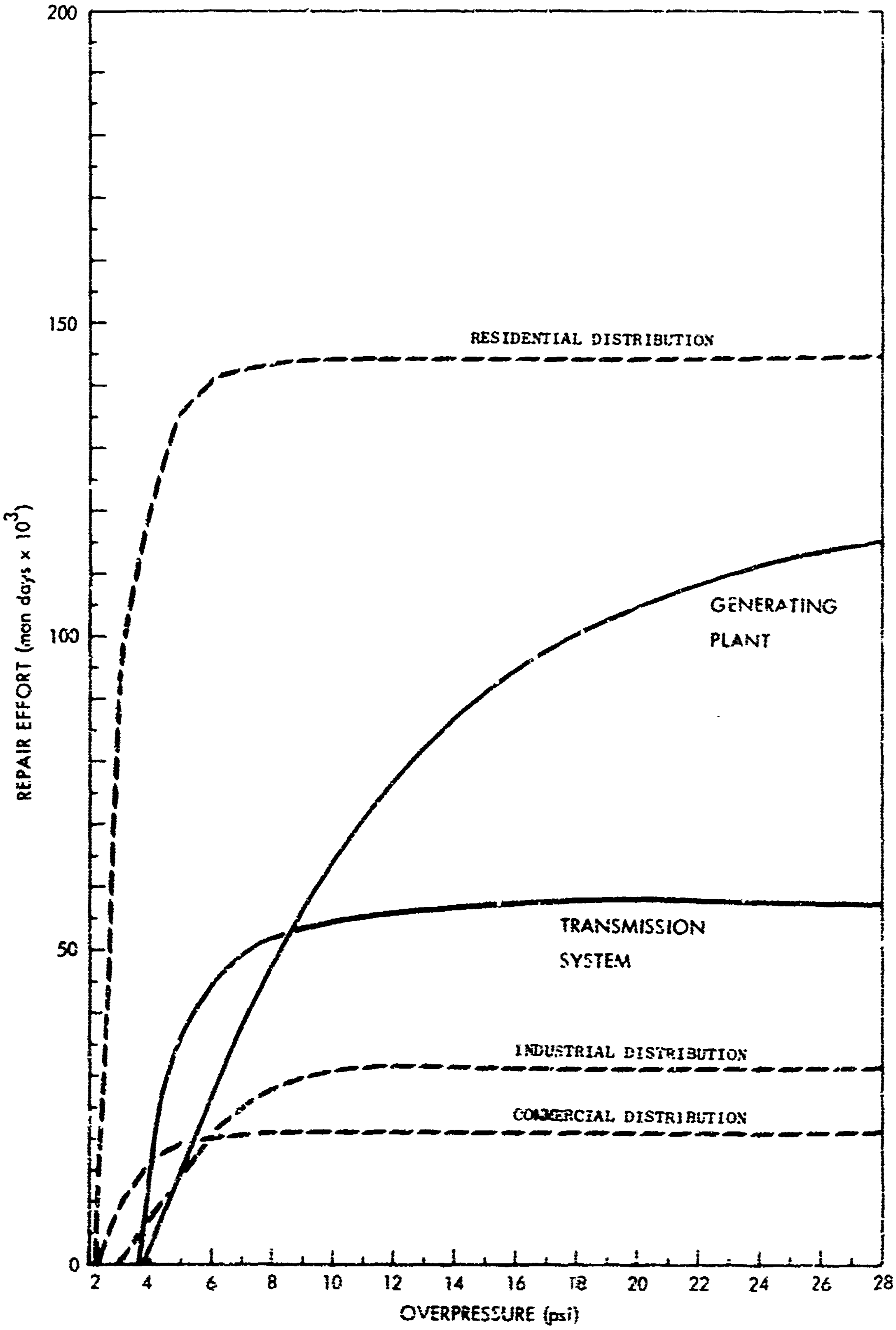
The results of the typical city repair analyses for gas and electric utilities appear in Figs. 7 and 8 respectively. From these plots, it is apparent that the major repair requirements are generated by residential distribution for both the gas and electric utilities. This would be expected, considering the predominance of individual dwelling units in any community. The commercial and industrial distribution subsystems, primarily because they serve fewer consumers, do not present as large a repair problem as does residential distribution. Some caution should be exercised in interpreting these results, since all repair estimates were prepared on the assumption that the city's postattack demand for gas and electric power would be essentially equal to its

* The repair effort for any mode could, of course, be calculated using the appropriate inputs for the mathematical model.



SOURCE: URS Corporation

Fig. 7. Comparison of Repair Requirements, Mode IB, for Gas Utility System for "Typical" City



SOURCE: URS Corporation

Fig. 8. Comparison of Repair Requirements, Mode IB, for Electric Utility System for "Typical" City

preattack demands. Although the scope of this study precluded consideration of how demand might change with the attack, we believe that postattack repair requirements would generally be significantly smaller than those predicted in terms of preattack demand figures. Because of the several unknown factors involved, we strongly recommend that further research be directed toward evaluating the effect that variations in demand would have on the repair requirements.

As can be seen by comparing Figs. 7 and 8, the electric utility presents a much greater repair problem than does the gas utility; for example, at 6 psi (an overpressure at which reconstruction, rather than abandonment, of an area is feasible) the total repair effort for the gas utility is 3,690 man-days and for the electric utility 254,000 man-days. The repair effort for the electric utility (again at 6 psi) could be decreased drastically (some 55 percent) if no attempt were made to serve residential consumers. Repair of the generating system, which represents less than 11 percent of the total repair effort at 6 psi, could probably be deferred or averted by using power imported from other locations. However, repair of the transmission system and a portion of the distribution system (approximately 20 percent of the total repair at 6 psi) would be unavoidable if any degree of system restoration were attempted.

Section 6
TIME-PHASED REPAIR ANALYSIS

The time-phased repair analysis, described in this section, was performed to determine repair requirements in terms of both man-hours and manpower skill classification. It also provided information on the number of workers which would be required during any given work period (work periods are defined here as being 8-hour shifts) and how these skills would be scheduled throughout the course of the repair program.

For simplicity, the time-phased repair analyses considered only two overpressure levels (4 and 9 psi) and only the I-B repair mode (i.e., skilled workers would restore the damaged systems to just short of their original condition).

APPROACH

The Repair Analysis Sheets (Appendix A) and the mathematical model for the typical city, together with the experienced judgement of our consultants, provided the basis for scheduling repairs with respect to time and manpower skill. It was necessary to balance such factors as crew size, working space, type of repair, equipment requirements, and job completion time to arrive at realistic schedules for performing utility system repairs. For the electric utility system, all major subsystems (i.e., generation, transmission, and distribution) were considered in the time-phased repair analysis. However, for the gas utility system only centralized subsystems (i.e., city gate stations, district regulator stations, peak shave plant, and compressor stations) were considered; distribution subsystems (i.e., underground pipes and service installations) were not included. The gas distribution subsystem was not considered (although presenting a major repair requirement at higher overpressures — see Fig. 7) because such repair as would be required — primarily repair of broken service connections — is most appropriately considered as a part of building repair or reconstruction.

Again a condition of uniform overpressures throughout the utility system was assumed. For comparative purposes two overpressure levels, 4 psi and 9 psi, which represent the range of damage levels for the subsystems involved, were considered.

RESULTS

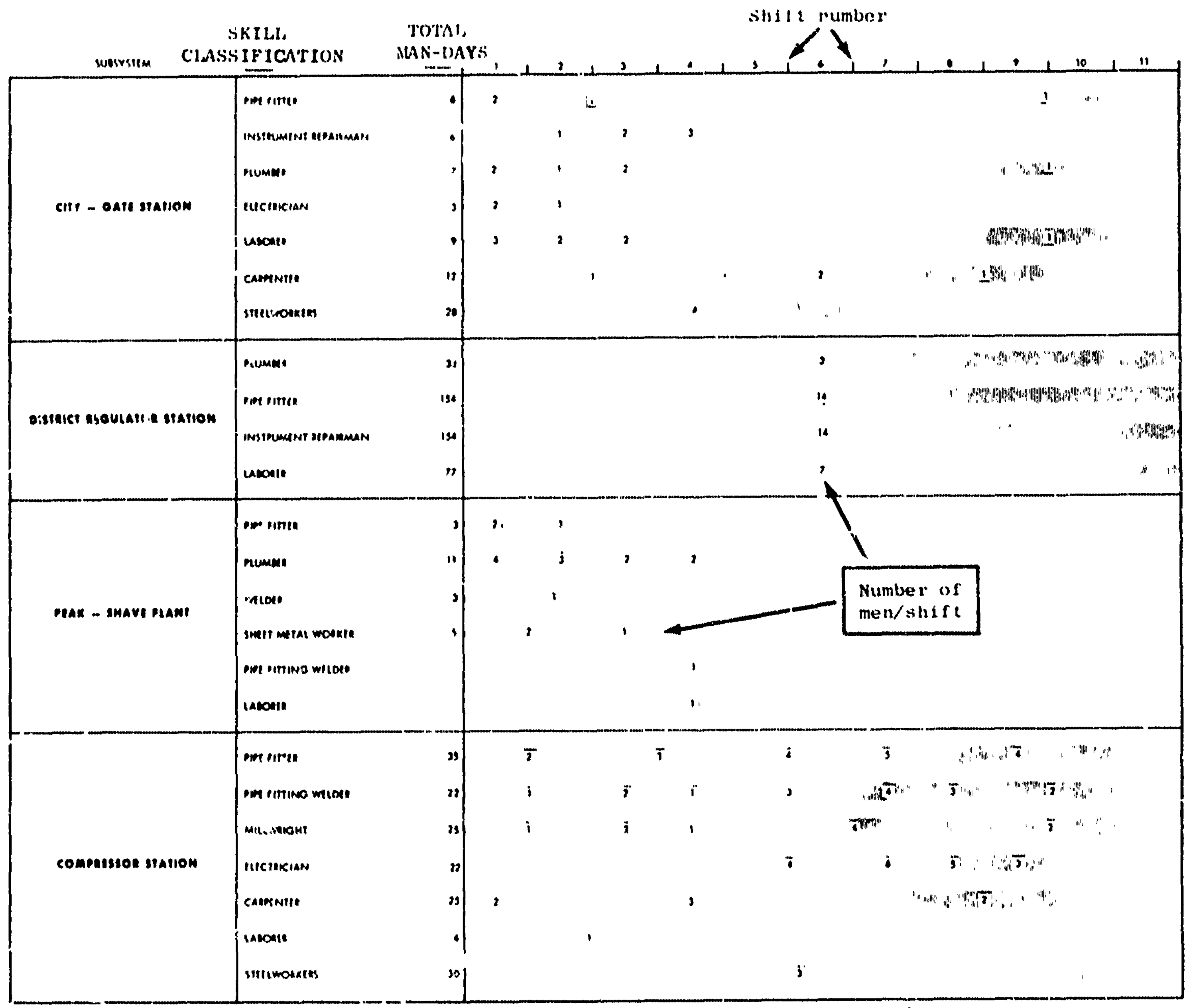
Figures 9 through 12 present the work schedules on a major-subsystem basis for the gas and electric utilities at 4 and 9 psi overpressure. Note that the figures making up the body of the table represent the number of men (of each manpower skill classification) required during any given work period. Presenting the scheduling on a major-subsystem basis provides a basis for determining whether a given subsystem warrants repair or should be bypassed.*

To impart a greater degree of flexibility to the time-phased repair scheme, the results have been presented as the total number of 8-hour work shifts required for each labor skill; thus, the total elapsed time required to repair a subsystem could be determined by deciding how many work shifts per day could be worked. However, using more than one shift a day for any length of time would necessitate a corresponding increase in the total number of skilled laborers required. The major labor constraints associated with the time-phased repair sequences for the various utility subsystems are as follows:

- Generating plant: (4 psi) boiler makers; (9 psi) boiler makers and steam fitters.
- Transmission system: (4 psi) linemen; (9 psi) linemen and electricians.
- Distribution system: (4 psi and 9 psi) linemen.
- City gate station: (4 psi and 9 psi) steelworkers
- District regulator stations: (4 psi) pipefitters and instrument repairmen, (9 psi) pipefitters.
- Peak-shave plant: (4 psi) plumbers
- Compressor stations: (4 psi) pipefitters and steelworkers; (9 psi) pipefitters.

---

* For example, the schedule might indicate at what point it would be advantageous to abandon a damaged power plant and utilize or repair an intertie with an external system, rather than repair the damaged plant.

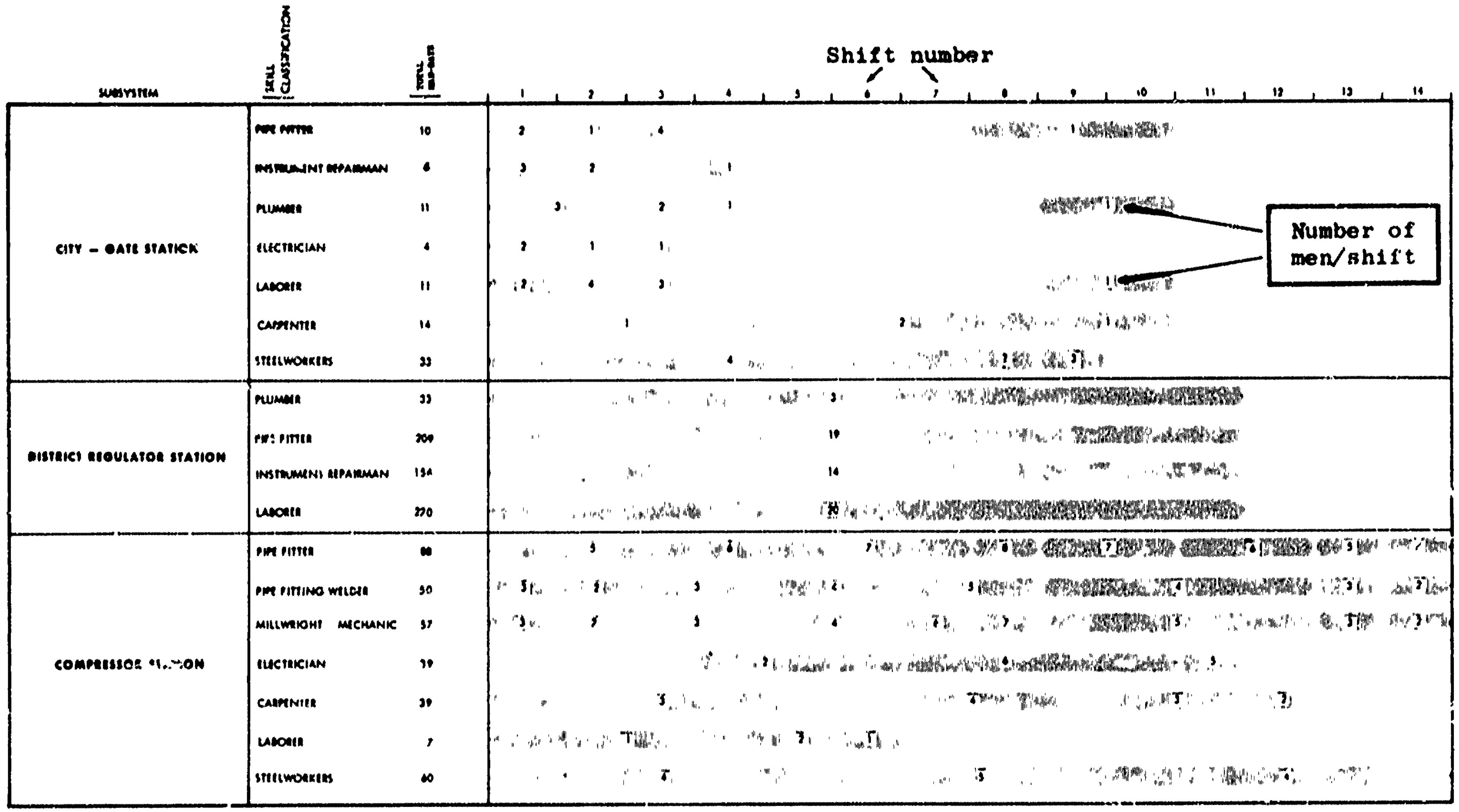


SOURCE: URS & Kennedy Engineers

NOTES: 1. Based on I-R repair mode
2. Shift length · 8 hr, i.e., 1 man-day = 8 man-hr

Fig. 9. Time-Phased Repair – Typical City Gas Utility, 4 psi Overpressure

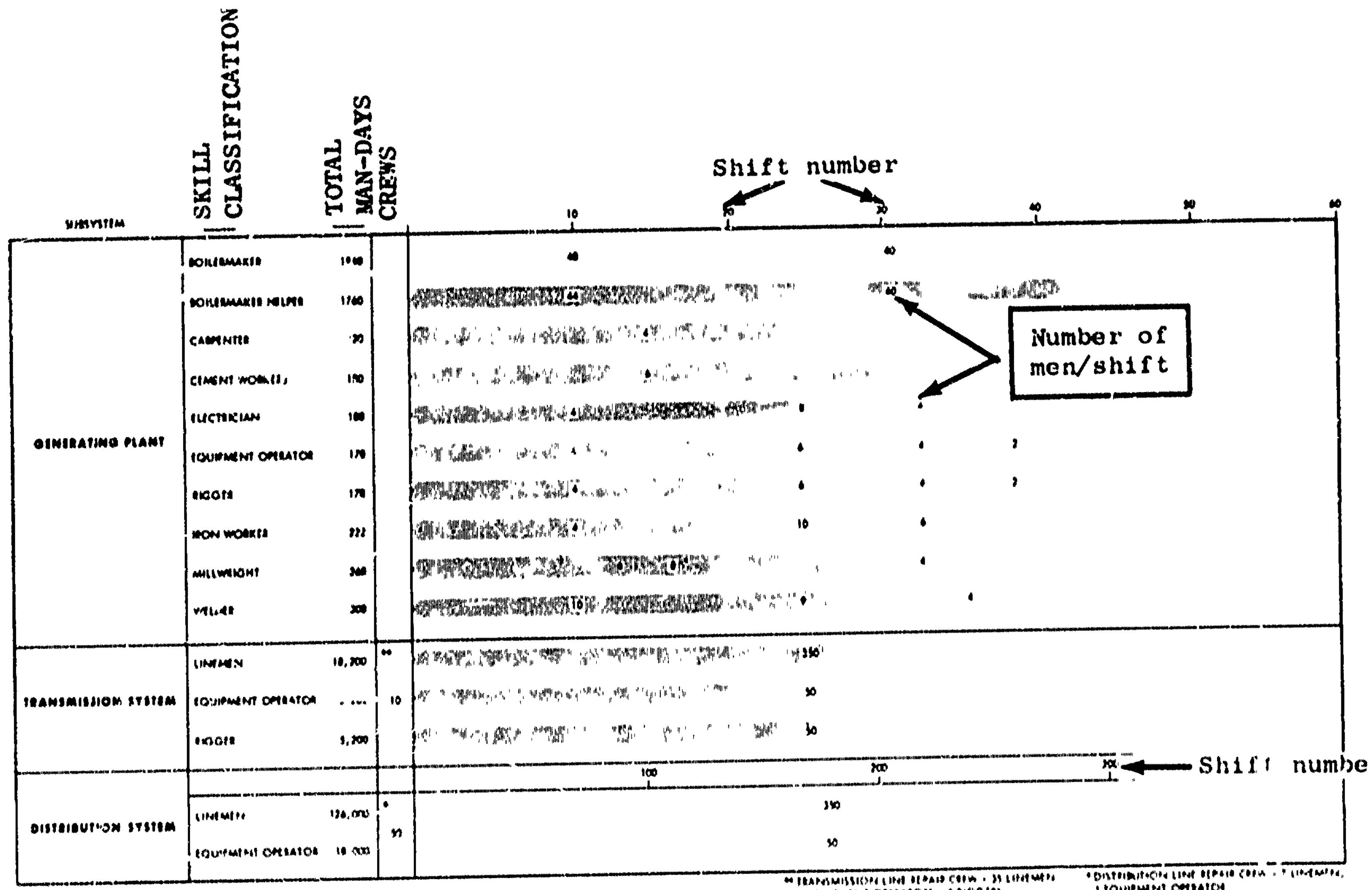
NOTES: 1. Based on I-B repair mode
2. Shift length = 8 hr, i.e., 1 man-day = 8 man-hr



SOURCE: URS & Kennedy Engineers

Fig. 10. Time-Phased Repair — Typical City Gas Utility, 9 psi Overpressure

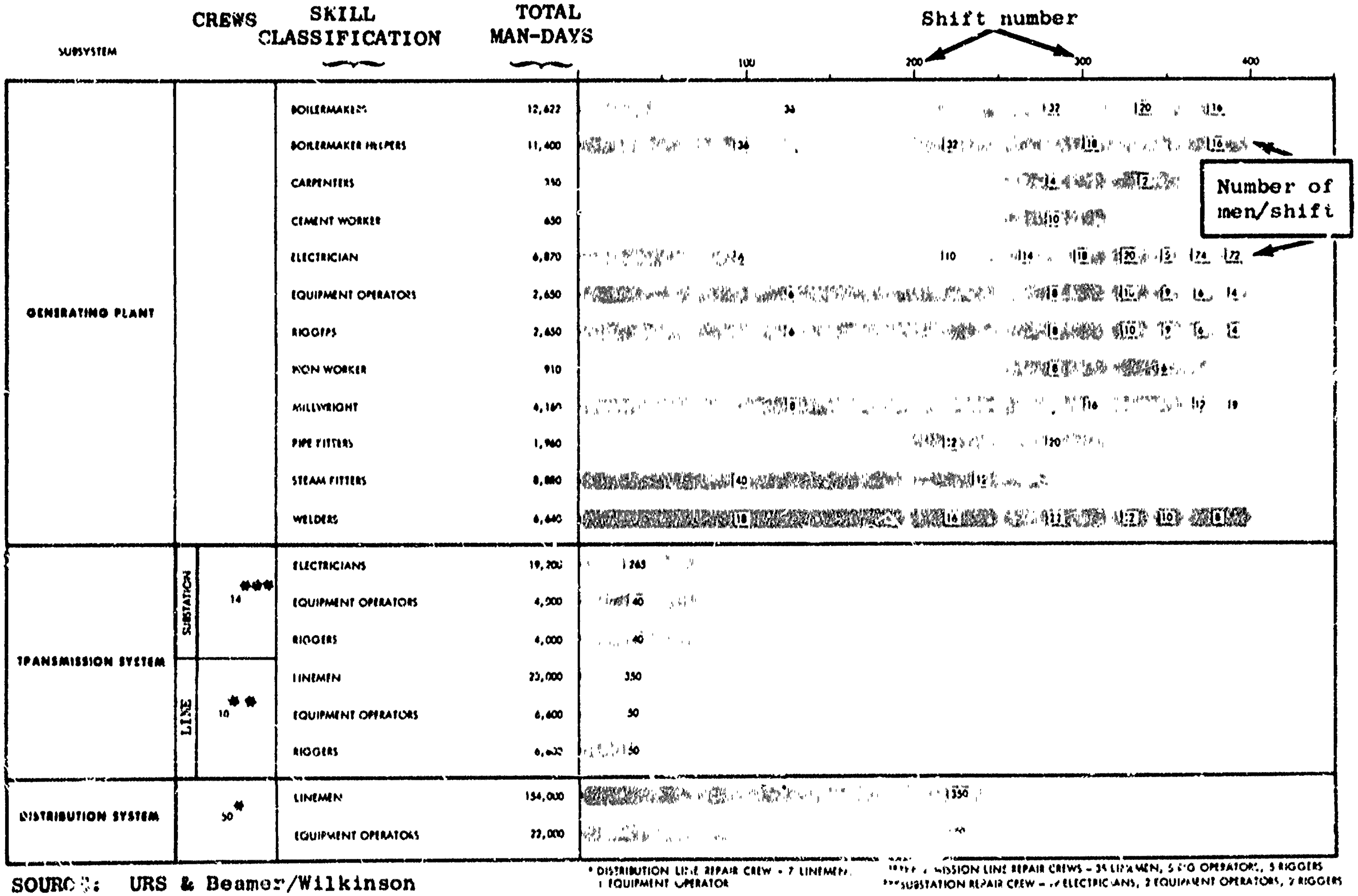
NOTES: 1. Based on I-B repair mode
2. Shift length = 8 hr, i.e., 1 man-day = 8 man-hr



SOURCE: URS & Beamer/Wilkinson

Fig. 11. Time-Phased Repair - Typical City Electric Utility, 4 psi Overpressure

NOTES: 1. Based on I-B repair mode
2. Shift length = 8 hr, i.e., 1 man-day = 8 man-hr



SOURCE: URS & Beamer/Wilkinson

Fig. 12. Time-Phased Repair — Typical City Electric Utility, 9 psi Overpressure

At lower overpressure levels (4 psi in this example) for the electric utility system, the distribution system requires the greatest period of time to repair, while the transmission system and generating plant can be repaired in approximately the same length of time. However, at higher overpressure levels (9 psi in this case), the time required to repair the generating plant increases considerably and equals that of the distribution system, with the transmission system requiring the least repair time. The three major subsystems (city gate stations, district regulators and compressor station) of the gas utility system at 4 psi overpressure require approximately the same length of time to repair, while at the 9-psi level the compressor station takes the longest time to repair, with the city gate station and district regulator station, requiring slightly less time.

Figures 13 through 16 are schedule summaries prepared by totaling the information given earlier on a subsystem-by-subsystem basis. At the far end of each summary sheet, two columns (mean number and maximum number of men required by skill), have been added to aid the reader in evaluating the overall and relative magnitude of the skilled labor necessary for the utility repair requirements.

The number of different skills required for repair varies for each utility and overpressure level. The electric utility system used 11 different labor skills at the 4-psi level and 13 skills at the 9-psi level. The gas utility requires 12 separate skills at 4 psi and only 9 skills at 9 psi (the reduction in number of skills is due to the change in criticality rating of the peak-shave plant, as discussed in Section 3). Approximately 50 percent of the necessary skills (i.e., carpenters, pipefitters, etc.) are common to both utilities. Two of the skills (i.e., linemen and instrument repair men) are unique to their respective utilities while the remaining required skills are common to the construction industry but related specifically to only one utility system repair (e.g., boilermakers, and steamfitters, for boiler repair). The time-phased repair sequences and summaries are based on having the required skills available; if alternate skills have to be used, the time periods given to repair damaged utility subsystems would probably double. A more realistic schedule could be promulgated by a utility following a nuclear attack using Figs. 9 through 16 as a guide.

A controlling factor in the scheduling of any task is the availability of the resources required to perform that task. As mentioned in Section 3, it has been necessary to assume that all manpower, equipment, materials, supplies, spare parts, special facilities, etc. would be immediately available as required. Therefore the time-phased repair analyses and repair schedules presented in this section are in error to the extent that this simplifying assumption is in error.

Because of the dispersed nature of the elements in the electric utilities transmission and distribution systems, there is virtually no constraint on how many workmen could be scheduled simultaneously. For this reason, we have presented the scheduling parametrically rather than in terms of some arbitrarily stated workforce size. Figure 17 depicts the length of time (in days) that would be required for crews of various size to repair distribution systems of various size at the 4-psi damage level. In most cases both the number of available repair crews and the circuit miles of a distribution system would be directly related to the size and population of a metropolitan area. Hence the repair time for the distribution system is found to be fairly constant for a community of any size. The range in the repair time which would be applicable to most communities is between 200 and 250 days, indicated in Fig. 17 by the shaded band.

The Use of Alternate Skills

The repair schedule assumed the availability of all the necessary labor skills that would be required. However, in some cases, requirements for a specific labor skill are so high that the probability of filling these requirements in any specific metropolitan area would be slight. Therefore, a qualitative analysis has been made of possible alternate labor skills that could be used to meet the skilled labor requirements.

The nature of our society is such that many individuals have the capability of performing tasks not closely related with their occupation. This is due in part to the fact that work force requirements (and hence the opportunity for employment) in specific areas has changed with time, causing people to adapt by acquiring new or further skills. The skills they leave behind become, for the most part, latent in that they cannot be inferred merely from a consideration of the person's current occupation. Other sources of latent skills might include:

NOTES: 1. Based on I-B repair mode
2. Shift length = 8 hr, i.e., 1 man-day = 8 man-hr

SKILL CLASSIFICATION	1	2	3	4	5	6	7	8	9	10	11	Men/Shift Ave.	Men/Shift Max.
PIPE FITTER	20	18		18	18		19	18	19		14	18.0	20
PLUMBER	9	7		5		3			4		3	4.6	9
WELDER		1										.3	1
SHEET METAL WORKER	2		1									.5	2
PIPE FITTING WELDER	1		2		3		4	3	2			2.1	4
LABORER OR UNSKILLED HELPER	11	10		9		7			8		7	8.3	11
MILLWRIGHT OR MECHANIC	1		2	1		4			2			2.3	4
ELECTRICIAN	2	1			4		6	5	3			2.3	6
CARPENTER	3		4		5		4	3		2		3.4	5
STEELWORKERS				7					3			5.3	7
INSTRUMENT REPAIRMAN	14	15	16	17				14				14.5	17
TOTAL NUMBER OF MEN REQUIRED DURING THIS WORK SHIFT	71	67	56	63	65		68	60	58	54	38	55.6	71

Shift number

Number of men/shift

SOURCE: URS & Kennedy Engineers

Fig. 13. Time-Phased Repair Summary — Typical City Gas Utility, 4 psi Overpressure

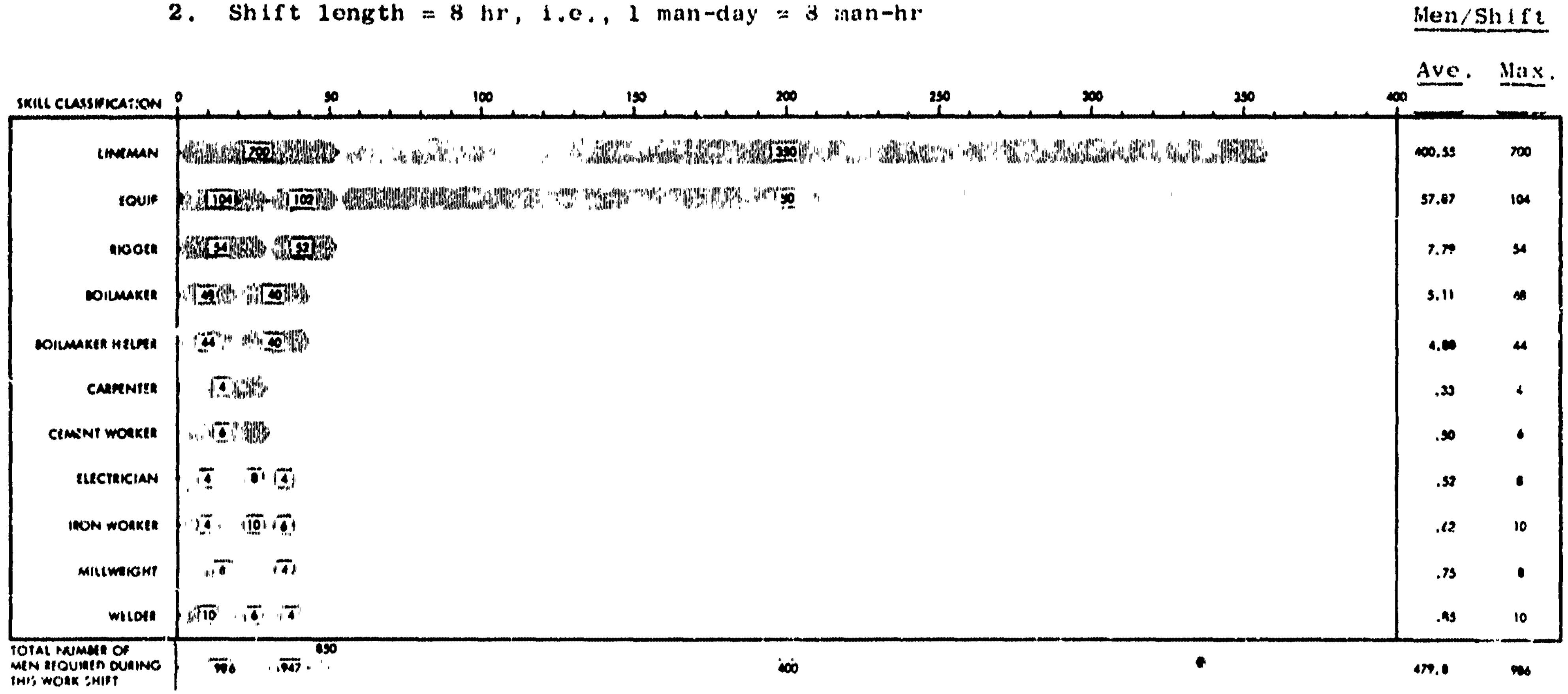
NOTES: 1. Based on I-B repair mode
2. Shift length = 8 hr, i.e., 1 man-day = 8 man-hr

SKILL CLASSIFICATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Men/Shift Ave.	Men/Shift Max.
PIPE FITTER	26	25	28	25		26		28	27		25	6	5	7	21.9	28
PIPE FITTING WELDER	3	2		3		4	5			4			3	2	3.6	5
MILLWRIGHT OR MECHANIC	3	2		3		4	6	7		5			3	2	4.1	7
ELECTRICIAN	2		1		2		6			7	5				3.2	7
CARPENTER			4		5		6		5	4	3	2			3.8	6
LABORER OR UNSKILLED HELPER	23	25	24	21	22	21	20		21		20				17.0	25
STEEL WORKERS			8			9		7	8			4			6.6	9
INSTRUMENT REPAIRMAN	17	16	14					14							11.4	17
PLUMBER		6	5			3				4	3				3.1	6
TOTAL NUMBER OF MEN REQUIRED DURING THIS WORK SHIFT	192	189	190	35	88	93	95	96	95	90	83	21	15		74.6	96

SOURCE: URS & Kennedy Engineers

Fig. 14. Time-Phased Repair Summary — Typical City Gas Utility, 9 psi Overpressure

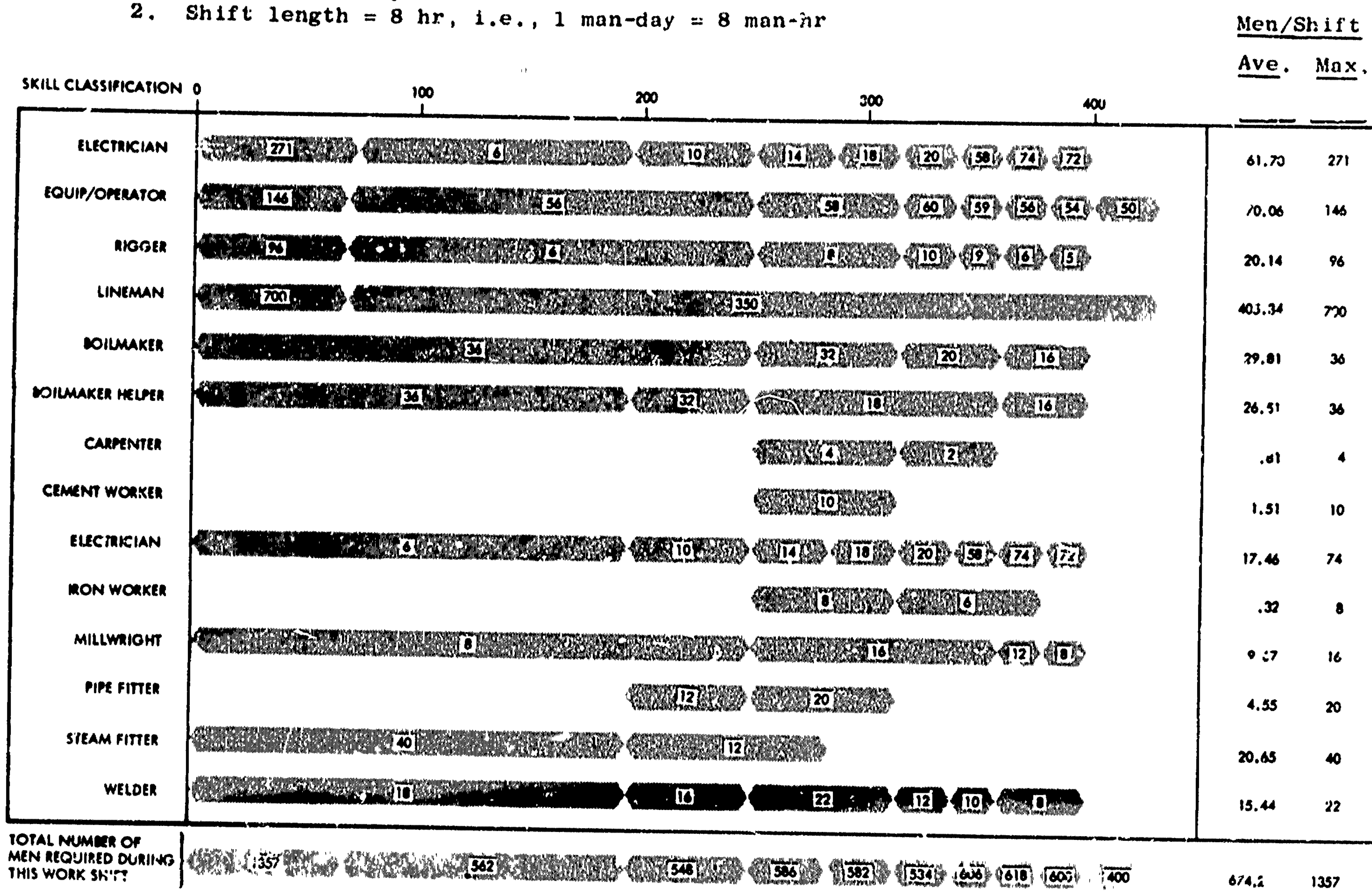
NOTES: 1. Based on I-B repair mode
2. Shift length = 8 hr, i.e., 1 man-day = 8 man-hr



SOURCE: URS & Beamer/Wilkinson

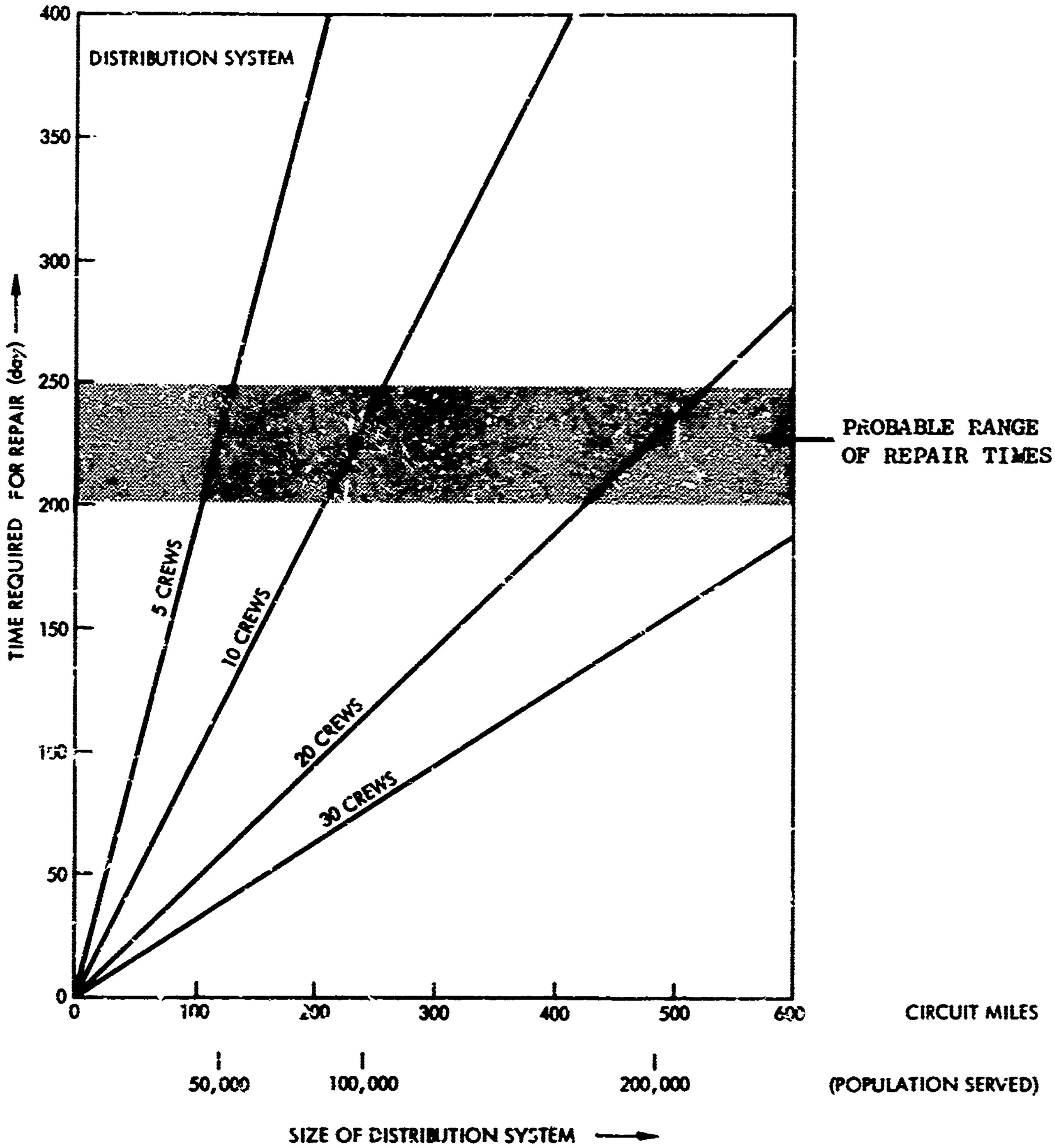
Fig. 15. Time-Phased Repair Summary - Typical City Electric Utility, 4 psi Overpressure

NOTES: 1. Based on I-B repair mode
2. Shift length = 8 hr, i.e., 1 man-day = 8 man-hr



SOURCE: URS & Beamer/Wilkinson

Fig. 16. Time-Phased Repair Summary — Typical City Electric Utility, 9 psi Overpressure



SOURCE: URS Corporation

Fig. 17. Change in Repair Time with Varying Crew Size: Electric Distribution System and 4 psi Overpressure

jobs held in youth, part-time jobs, military training, hobbies, or even jobs held by family members.

Nordlie and Vestermark (Ref. 24) discuss this property of pluralistic, industrial forms or society (such as is represented by the contemporary United States) and relate it to our potential for recovery following a nuclear attack. In their words, "American society appears to have important redundant capacities for meeting massive upheaval and degradation of pre-existing standards, and for redirecting individual behaviors and social processes toward long-term recovery. This redundancy of capacity means that much can be subtracted from American physical and social resources, while still leaving a minimum base for recovery."

To apply this philosophy to the postattack restoration of gas and electric utility service, we can consider the availability, in the populace, of those persons capable of making significant contributions to the restoration task. To be sure, the great majority of these persons would not be able to function in all capacities as well as a skilled utility worker, nor would they require as little supervision. However, in many instances their contribution might well make the difference between having service restored at a reasonable date rather than having to wait a prohibitive time for the utility company's employees to complete the restoration.

In view of the fact that the "latent" capabilities of individuals are not reflected in available industrial manpower statistics, it is recommended that studies be performed to determine the type and extent of these latent talents. One possible research approach would be a survey of randomly selected individuals in an industrial community to ascertain primary and secondary skills.* The findings of such a study would provide data on the extent to which interchangeability of labor is possible. A second approach would be for industry (hopefully with the cooperation of labor unions) to develop files on worker capabilities for all employees.

* Such a survey could be similar, but on a much smaller scale, to that conducted periodically by the National Science Foundation of professional and technical personnel.

In the absence of such specific information on latent skills and skill overlap between various job classifications, we are limited to a qualitative discussion of manpower interchangeability and substitution. Table 5 was prepared by using the occupational title information and numerical indexing system given by Ref. 25 and has been included to suggest several general areas wherein an appreciable degree of job interchangeability appears feasible.

Special Equipment

Many of the repairs that would be performed in the utility systems require the use of special heavy equipment, such as cranes, hoists, trenching machines, compressors, and welding machines. Although this equipment has been delineated on the Repair Analysis Sheets in Appendix A, its availability was not taken into account for the time-phased repair analysis. In actuality, the availability of such heavy equipment would greatly affect the speed at which a utility system could be repaired and, in the case of the electrical and gas distribution systems, could well be the major constraint as to the total time required to repair these systems. While it is realized that utility companies themselves own and operate many pieces of special equipment, for economical reasons they rarely have more than is necessary for the day-to-day maintenance and repair of their total systems. With the massive repair efforts that would be required at moderate or higher overpressures, the resources of both major and minor private contractors would have to be sought if the repair effort is not to extend over an inordinate length of time.

Table 5

INTERCHANGEABILITY OF LABOR SKILLS FOR VARIOUS TASKS

Repair, installation, and operation of machinery
Auto mechanic
Industrial mechanic
Operating engineer
Machinist
Millwright
Repair, installation, and operation of piping system
Pipefitter
Plumber
Steamfitter
Boiler maker
Welder (specialized)
Repair, installation, and operation of electrical systems
Electrician
Lineman
Electronic technician
Instrument technician
Repair and construction of miscellaneous structures
Structural iron worker
Rigger
Carpenter
Welder (general)
Mason
Sheetmetal worker

SOURCE: URS Corporation and U.S. Department of Labor

Section 7
PREATTACK PLANNING AND ALTERNATE PROCEDURES

PREATTACK PLANNING

The results of this study, particularly the mathematical model, can be used by utilities in preattack planning and attack-implemented emergency operations. Careful preattack planning using realistic damage estimates could significantly improve the utilities' capability to provide electric power or gas following a nuclear attack. One approach to preattack planning could be as follows:

- Utilize the mathematical model to predict the postattack damage situation and repair requirements. (If a range of effects is desired, several different weapon sizes and weapon locations could be used to approximate light, medium, or heavy attacks on the utility system.)
- Integrate results of the model with general area damage estimates prepared by OCD.
- Identify the relative magnitude of demand sources (consumers) and rank these on a priority basis.
- Identify and rate the predicted postattack capability of "imported" gas or electric power sources (other transmission systems, electric generating plants, etc.).
- Determine which parts of the system should be hardened,* repaired immediately postattack, or given other special attention to improve their probability of performing postattack.

---

* Elements can be hardened permanently or only temporarily. Permanent hardening should be considered for very critical elements, without which the system could not function at all. Examples of such hardening might include the burying of electric transmission lines or housing city gate stations or key substations in heavily reinforced concrete buildings or vaults. Temporary hardening could be applied during periods of increased readiness and might be more applicable to elements of moderate criticality or even semi-critical elements. Examples of temporary hardening might include sandbagging instruments and measures to shield them from missile damage or tying down transformers to prevent overturning.

- Plans for postattack operations should consider the prepositioning of men and equipment so as to increase their survivability following a nuclear attack. One possible method is the concept described in Ref. 12, which employs engineering yards located around the perimeter of a city as staging areas wherein men and equipment would be stationed prior to a nuclear attack. The stockpiling of vital supplies and their possible distribution to points outside the city should also be included in emergency plans. Postattack procedure should also be delineated for the cannibalization of damaged utility elements in low-priority areas to speed the repair of similar damaged utility elements in high-priority areas.

- Duplicate utility system maps should be prepared and disseminated to the various locations where repair parts would be based. This would enable repair personnel to quickly locate critical areas in the utility system for repair or isolation.*

ALTERNATE OPERATING AND REPAIR PROCEDURES

The I-B repair mode, toward which the preceding sections have been directed, implies the use of certain operating and repair procedures which differ from normal practice. The use of such alternate procedures is especially applicable to the restored electric utility system. The gas utility system, being inherently less flexible in nature, cannot take advantage of alternate operating procedures without losing so much capacity as to be classified as Mode "C." However, alternate repair procedures can be employed. These alternate repair procedure involve the substitution of normal gas utility components by similar components intended for use in water, petroleum, or chemical piping installations. Simple valves, piping, and some pressure instruments could be used with virtually no modifications and no degradation of system operability. Such substitutions are possible partly because the gas system is basically very simple and partly because

* It should be noted that a primary constraint to shutting off all or any portion of a system is knowledge of how to do so, i.e., where control points are located and how they are actuated.

gas system components are generally stressed to only a fraction of their capacity (with respect to operating pressures, at least). It should be noted that the gas and electric utility systems are basically different in this respect. Electrical components are designed and rated for a specific use and cannot generally be interchanged very freely (e.g., one cannot replace the elements of a 34-kV system with those of a 12-kV system). While it is possible to substitute some elements with similar units of a higher rated capacity, this practice has its limits also.

The more important deviations from the normal operation and repair of the electric utility are discussed below (detailed descriptions are given in the Repair Analysis Sheets, Appendix A):

- Automatic Controls. When automatic controls have been damaged, the simplest alternate operating procedure is to resort to manual operation. This would, however, increase the required size of operating crews by three or four times. Manual controls would allow partial or full operation while an expedient control system was being rigged.

- Transformers. Large distribution of transmission transformers, when overturned, can suffer coil damage which is virtually impossible to repair in the field. Under peacetime conditions, transformers suffering coil damage are normally shipped to the manufacturer for repair; however, there are only four large manufacturers of transformers in the United States, and they are located east of the Mississippi River. Consideration then would have to be given to converting large manufacturing or repair facilities (such as shipyards) to repair large transformers. A possible alternate operating procedure in the case of loss of large step-down transformers would be to operate the transmission or distribution lines at a reduced voltage and use a number of smaller transformers; although this procedure would be severely inefficient due to large line losses, it would provide electricity, where needed, in an emergency.

- Small Pole-mounted Distribution Transformers (25 to 50 kVA). These represent an easier repair problem than the large transformers because of their smaller size. Under normal peacetime conditions, most utility companies do not repair this size transformer, but simply replace it with a new one. However, due to a shortage of supplies following a nuclear attack, this approach would be unfeasible, and small repair facilities or machine shops would have to be converted to repair the damaged transformers.

- Bus Structures. When a bus structure has collapsed or become so severely deformed that electrical clearance is not maintained between bus bars, rebuilding of the bus structure is necessary. An expedient method to speed repair would utilize wood instead of steel in the bus structure. Operation of the bus and transformers at reduced voltages may also be feasible.

- Distribution System. The major damage to a distribution system occurs when power poles are snapped off, usually several feet aboveground. Not only are the poles and electrical conductors broken, but the porcelain insulators mounted on the crossarms may be cracked or broken (as mentioned above, distribution transformers will also be damaged). The normal procedure when a distribution pole is broken is to replace it with a new pole. However, with the scarcity of supplies that could be expected following a nuclear attack, a different procedure would probably have to be adopted to make the necessary repairs. One alternate repair method would be to strap the broken poles to the stubs remaining in the ground. Broken insulators could not be repaired by cementing but might be replaced with resin-impregnated wood to anchor the conductors to the crossarms.

- Start-Up Power. When an electric generating plant is subjected to a sudden variation in load,* the plant's safety devices automatically disconnect the plant from the system and shut it down. To restore a generating plant to service requires electricity to power the plant auxilaries (e.g., automatic controls, pumps, fan motors, etc.). This power requirement is approximately 10 percent of the plant's generating capacity (i.e., a 600-MW plant would require 60-MW start-up power). Typically, in this country, generating plants rely on system interties to provide start-up power and infrequently have emergency generators (capable of independent operation) to supply the required power. Therefore, alternate procedures for supplying start-up power would have to be used where system interties have been destroyed.** One such method would be to employ a diesel-electric-locomotive as an independent source of power.

---

* A recent multistate blackout was caused when a 230-kV transmission line short circuited; a single nuclear weapon could cause several such failures in one metropolitan area.

** This would be particularly important where a plant suffers only minor damage and the major obstacle in restoring it to service is lack of start-up power.

Section 8
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

A number of conclusions based on the results and data presented herein are reported below.

Comparison of Gas and Electric Utilities

Although gas and electric utilities serve many of the same consumers, they are dissimilar with respect to both vulnerability to nuclear attack and the subsequent repair requirement. Gas utilities within metropolitan areas are relatively simple in design and operation; most critical elements are located underground, with the result that damage to a major portion of the system (i.e., pipelines) occurs only at very high overpressures. The repair effort for aboveground elements, which are damaged at overpressure levels of less than 12 psi (where, coincidentally, the survival of at least some personnel and facilities is probable) is relatively small (predictions for the typical city are 40,000 man-days at the 9-psi level). Electric utilities, on the other hand, are complex in design and operation, most critical elements are aboveground, major damage occurs in the 5 to 12-psi range, and repair effort is massive (predictions for the typical city are 284,000 man-days at 9 psi).

Damage to Components and Continuity of Service

The damage sustained by the various components of the utilities and the subsequent repair required determine the overall response and probable availability of utility service. At very low overpressures (i.e., 1 to 2 psi) electric utility service would be temporarily disrupted immediately following the attack until such time as repair crews could make minor repairs, reset protective devices, and possibly revert to manual control of operations, a matter of some hours if personnel are available. However, this restoration time would be drastically increased if start-up power for the generating plant were unavailable — a not unlikely eventuality. At this overpressure level, critical elements within gas utilities would normally be unaffected except in rare cases where controls at city gate stations or cross-country terminals incur damage; if personnel were available, repairs could be completed before service to the consumer was interrupted.

At overpressure of 3 to 4 psi, electric utilities would sustain moderate to serious damage to distribution systems (primarily from broken poles and trees falling across lines), and large sections of the city would be without power for a matter of days or weeks even if repair crews were available. However, those sections of the city served by underground distribution systems (primarily the central business district), would suffer shorter outages only if aboveground transmission lines feeding the underground system remained undamaged. Some failures might occur in a steam electric generating facility at this overpressure level primarily due to damaged control systems, but such failures would be of relatively short duration if repair crews were on hand and manual operation could be instituted. Further, interties with unaffected areas might be used for providing power to damaged areas (assuming other heavy-load areas were not affected). The gas utility would be expected to sustain no additional damage in this range.

At a somewhat higher overpressure level (i.e., 4 to 6 psi), all aboveground distribution systems and most of the transmission system of the electric utility would be severely damaged and inoperable. Even if repair crews and replacement parts were available, service over the entire city would be disrupted and could not be resumed (even with a massive repair effort) for a matter of weeks or months. Even portions of the city served with underground lines would be affected since the transmission system, most of which is aboveground, would have been severely damaged. The electric generating plant would sustain considerable damage, which would require, at a minimum, a repair effort of many months. Substations would also be damaged to a considerable extent. Imported power from interties would not be usable until such time as transmission and distribution systems and substations within the city were repaired or rebuilt; however, some isolated areas might be served earlier by building special lines from interties to serve them. At this overpressure level, the gas utility's system itself would receive little additional damage, although many service connections would be sheared off with building collapse. Since numerous leaks would result, much of the distribution system would have to be shut off for both conservation and safety reasons. It would be preferable to shut off only affected portions of the system at district regulators. However, in some systems, such an arrangement may not be possible (due either to lack of knowledgeable personnel or inaccessability of the area) and the entire city might have to be shut off at city gate station.

At higher overpressure levels (6 to 8 psi) the distribution and transmission systems of the electric utility would be so severely damaged that rebuilding would be undertaken only in the most unusual circumstances; even the reuse or salvage of parts would be unlikely. Above 8 psi, no possibility of repairing the distribution and transmission systems is forecast. If it were decided to restore service following such heavy damage, new construction employing new or cannibalized materials would be required. Damage sustained by generating facilities would rise sharply at about 10 psi but repair would still be within the realm of feasibility if replacement parts were available. Above 12 psi, the boilers would be totally destroyed and the frame of the building excessively distorted; restoration would not be feasible. At 10 to 12 psi serious damage to aboveground gas pipelines (such as river crossings) and appurtenances would be widespread. However, with trained crews, equipment, and replacement parts, system integrity could be rather rapidly reestablished, although service to consumers (presumably in areas experiencing considerably less damage) could not be resumed until the affected portions of the system could be purged and tested. Where air-induced or direct ground shock is an important factor, extensive damage to the underground pipe-line system would occur. Presently available data are insufficient to allow any reasonable estimates to be made concerning the occurrence or degree of damage resulting from ground shock.

Adequacy of Supplies and Spare Parts

The postattack demand for replacement parts would be high; while their probable availability would be low. One possible solution to this dilemna is cannibalizing or salvaging needed parts from portions of the system not in use. Another potential solution is to employ alternative operating procedures although these inevitably degrade the system's reliability and safety and usually it's output as well (however, the effects of the attack would probably reduce demand more significantly than it would system output capacity).

Certain critical elements appear to impose special constraints upon the restoration of the utility system as a whole. The constraints common to such elements are: (1) the item is irreparable, at least by ordinary standards;

(2) spare parts are not available in adequate quantity; (3) alternate operating procedures which can bypass the damaged element are not feasible. Those critical elements believed to present such constraints are all found within the electric utility and are described below.*

- Large Transformers. These units are essential in stepping up and stepping down voltages between the generator, the transmission system, and the distribution system. Although they are relatively "hard," coil damage is probable if overturning occurs. For repair they must be returned to the manufacturer's plant (there are only four major manufacturers in the nation, all east of the Mississippi River) for complete rebuilding. Because of the high cost of such transformers and because most are custom-made, standby and spare units are kept to a minimum. Alternate operation to bypass such large transformers are possible but only at the sacrifice of most of the operating capacity of the system.

- Porcelain Insulators. These essential components of all transmission and distribution lines are easily broken and, being a vitreous material, are irreparable. No feasible alternate procedures are apparent (the use of insulated conductors is of very limited applicability because of the very small stockpiles of such cable). Replacement stocks of insulators are relatively small since the normal breakage rate is low. These stocks would be completely inadequate in the face of a major catastrophy.

- Small Pole-mounted Transformers. Distribution transformers present a severe constraint in that they are widely used and are usually damaged when poles break. They could probably be rebuilt locally (although normally utilities prefer to scrap them and buy replacements) by converting available manufacturing capacity within the community to this purpose.

Mathematical Repair Model

The repair effort required for damaged gas and electric utilities can be related to overpressure by an exponential relationship which considers overpressure (and related weapon effects), degree of restoration, and qualification of repair crews. The repair model can be used by real utilities and real cities for predicting repair requirements under various assumed attack conditions, thereby providing a better basis for planning and training.

* The components of the gas system show a high degree of interchangeability (e.g., a water valve can be used to control gas flow) as well as a large safety factor (e.g., a pipe may be rated for 25 psi but may well be usable at 500 psi), so that the potential source of replacement parts and supplies is very broad. This flexibility is not true of the electrical system, in which components must be accurately rated and precisely matched.

Requirements for Manpower

The work force required for repairing gas and electric utilities would include most of the major construction skills. It is probable that major shortages in some skills would occur even in the absence of personnel casualties and would certainly be accentuated if casualties occurred. The interchanging of skills would probably be practiced widely to reduce the problems of manpower shortage; such interchanging has definite limitations, however, and is never a completely satisfactory solution. Repair effort is expected to roughly double where utility trained crews are replaced with crews composed of workers having different but related skills. When using alternate skills, some system degradation would be likely to occur, i.e., system reliability and safety might suffer and outages might be more frequent and severe.

Within limits, skilled labor can be substituted for damaged components, and conversely, new components can reduce the requirements for skilled labor. In time of disaster, the payoff between these two resources would have to be adjusted to meet the immediate situation.

Time-Phased Repair

The study of time-phasing of repair effort provided data on the size of the work force required, the total time required for restoration, and the specific skills, and alternate skills required. These data can provide guidance to real utilities as to the potential magnitude of the repair problem they themselves might face and can allow them to assess their own capabilities to meet such an exigency.

Requirements for Preattack Planning

Utilities, because of their frequent encounters with natural disaster, have some basic capability for meeting nuclear disaster. However, additional planning and training directed primarily at problems associated with nuclear attack would substantially increase the utility's ability to remain in operation in the event of light damage and to resume operations more rapidly in the event of heavier damage. Present planning should be changed to recognize that, in the event of a nuclear attack, localities would be isolated and dependent upon their own resources. This situation is unlike peacetime disasters, in which repair crews and supplies can be flown in from adjacent, unaffected areas.

Since, control equipment invariably fails prior to the main components of the system, personnel should maintain their skills in alternate techniques which permit manual control of operations. Additional consideration should also be given to protecting working personnel to maintain the continuity of service during attack.

Other Potential Problem Areas

Insufficient data are available on the response of certain elements (such as large turbo-generators and gas regulators to blast and underground pipelines to ground shock), and a need for further analyses and testing is indicated. A possible source of major damage, noted but not explored in this study, is the possibility of system self-destruction, which might occur if the system's protective devices (i.e., circuit breakers in the transmission distribution system and speed control devices in the turbo-generators) were simultaneously or sequentially disrupted by the advancing blast wave. Possible damage could range from scored bearings and thrown turbine blades to propelling the rotor through the roof (either from weapon effects proper or from a sudden drop in the electrical load). Until such time as definitive answers can be provided to this possible danger, it may be wise for the electric utility industry to plan for an ordered cutback of service as the threat of nuclear attack increases. They could either shut down and secure a portion of the generating capacity or, alternatively, place it on spinning reserve (i.e., the boiler producing steam and the generator turning but under no load).

In only a few instances would hardening of critical elements materially increase the probability of restoring a damaged utility as a whole. One notable exception is the large transformers, which are essentially irreplaceable once damaged by overturning. Additional bracing to reduce the likelihood of overturning might be a very worthwhile and reasonably low-cost investment.

RECOMMENDATIONS

Based upon the results of this study (including problem areas which were only briefly considered) the following are suggested for future research:

1. Apply the mathematical repair model (Section 4) to the real utility systems being surveyed as a part of the Five-City Study. Such a study would (1) provide basic inputs for the postattack recovery portion of the Five-City Study and (2) provide planners - both governmental and industrial - with a better understanding of the problems facing the utility industry in the postattack recovery period.

2. Determine if interchangeability of labor skills is sufficiently flexible to provide the skilled manpower necessary to meet post-attack recovery and restoration demands. Interchangeability of skills has been discussed (Section 6) as being contingent upon both designated job skill and previous training, but the relationships between these factors has not been established.

3. Investigate the changes in demand for utility services during and following nuclear attack. In the postattack period, a decrease in the number of consumers and changes in community consumption patterns could both act to alter repair requirements, probably decreasing them appreciably.

4. Determine the physical resources needed, on a nationwide basis, to restore, to the degree required, damaged utility systems and estimate the postattack economics capability to provide such resources. If severe shortages and constraints are found probable, preattack stockpiling of such resources may be advocated.

5. Extend the findings of the present study to include nuclear electric generating plants which, within 15 years, are expected to rival conventional thermal plants as sources of electrical power. Although both types of generating plants have many elements in common, the effects of nuclear attack on a nuclear reactor and its sophisticated control systems are poorly understood.

6. Investigate possible major damage to electrical utility systems resulting from simultaneous loss of controls and safety devices in both generating and distribution systems due to blast effects, electromagnetic pulse, or other weapon phenomena not investigated in this study.

7. Develop through analysis and/or tests additional data on the response of critical elements, including large transformers, circuit breakers, control panels, transmission towers, gas regulators and relief valves, for which existing data are inadequate.

Section 9
REFERENCES

1. Armour Research Foundation, Study of Vulnerability of a Thermal Electric Power Plant to Air Blast, 15 March 1954 (CONFIDENTIAL)

2. Consoer, White, and Hersey, Vulnerability and Recovery of Public Utility Plants From the Effects of Nuclear Weapons, Unit I: Power Plants, 1 July 1961

3. Fernald, O. H., Critical Industry Repair Analysis: Electric Power, Advanced Research, Inc., 1963

4. Wood, R. V. H. et al., Effects of Atomic Weapons on Electric Utilities, WT-1173. Edison Electric Institute and Federal Civil Defense Administration, 14 June 1965

5. Stephenson, J. M., Earthquake Damage to Anchorage Area Utilities - March 1964, U.S. Naval Civil Engineering Laboratory, 26 June 1964

6. Mc Fadden, F. and C. D. Bigelow, Development of Rapid Shutdown Techniques for Critical Industries, Stanford Research Institute, Menlo Park, January 1966

7. Defense Electric Power Administration, Protection of Electric Power Systems, June 1962

8. Defense Electric Power Administration, Vulnerability of Electric Power Systems to Nuclear Weapons, Government Printing Office, $1.75

9. Federal Power Commission, Report to the President, Northeast Power Failure, November 9 and 10, 1965, December 1965

10. Carroll E. Bradberry and Associates, Description, Inventory, and Damage Assessment of Engineering Resources, December 1965

11. Van Horn, W. H., C. R. Foget, R. L. Fuller, and M. B Hawkins, Analyses for EOSD Engineering Programs; Emergency Operations System Development, Phase I Analytical Report--Engineering, URS 657-7, URS Corporation, December 1965

12. Foget, C. R., R. D. Bernard, and W. H. Van Horn, Final Systems Analysis for EOSD Engineering Programs, URS 672-10, URS Corporation, March 1967

13. American Gas Association, War Protection of the Gas Industry, March 1942

14. Tucker, P. W. and G. R. Webster, Effects of a Nuclear Explosion on Typical Liquefied Petroleum Gas Installations and Facilities, WT-1175

15. Corfield, G., Effects of a Nuclear Explosion on Typical Natural and Manufactured Gas Underground and Above-Ground Installations, Including Appliances in Houses, WT-1176, Civil Effects Test Group, and the American Gas Association, 11 June 1965

16. Thayer, S. B. and W. W. Shaner, The Effects of Nuclear Attacks on the Petroleum Industry, Stanford Research Institute, July 1960

17. National Petroleum Council, Civil Defense and Emergency Planning for the Petroleum and Gas Industries, 19 March 1964

18. Morris, P. and J. Edmunds, Effects of Nuclear Detonation on Wooden Communications, Power Line Poles and Ancillary Equipment, URS Memo 67-669-1, URS Corporation, February 1967

19. Glasstone, S., ed., Effects of Nuclear Weapons, Department of Defense, 1962

20. Zaccor, J., Personal Communication, May 1967

21. Electrical World, June 12, 1967

22. McMasters, Alan, Personal Communication, February 1967

23. Cone, D. R., et al., "Communications Equipment and Systems to Support Intrastate Civil Defense Operations Circa 1970", Stanford Research Institute, Dec. 1965

24. Nordlie, P. G., and Vestermark, S. D., Civil Defense in Postattack Socity, Human Sciences Research, Inc., Feb 1967

25. Dictionary of Occupational Titles, U.S. Department of Labor, Bureau of Employment Security (1965), third edition

Appendix A

REPAIR ANALYSIS OF UTILITY SYSTEMS

REPAIR ANALYSIS OF GAS UTILITY SYSTEMS

Natural gas systems are generally considered to consist of sources (gas wells), processing facilities, transmission pipelines and appurtenances, and distribution systems. Since the majority of gas wells and processing facilities are in remote locations, far from metropolitan areas, they have not been included in this study. Similarly, transmission mains were examined only superficially.

The system studied in depth is shown in Fig. 1 as a block diagram and in Fig. 3 as a list of elements, each of which is keyed by number (e.g., G-13a) to the following Repair Analysis Sheets.

The following qualifying and explanatory remarks apply:

- The time required to purge (displace air from) gas distribution lines has not been included in the sheets, since it depends heavily upon the size of the damaged system and cannot be expressed on a general, element-by-element basis.

- The time required to remove water from flooded gas lines has not been included, since this depends primarily upon the individual system's vulnerability to flooding* and the size of the system.

- Those items assumed to be generally furnished as the complement of a typical utility repair truck or readily available from local sources have not been included in the Repair Analysis Sheets as required equipment or supplies.

The following abbreviations have been used on the Repair Analysis Sheets:

* It should be noted that many newer distribution lines are not graded and would require considerable effort to drain.

Equipment

PF	Pipe fitter's or ordinary plumber's tools: vise, pipe wrenches, cutter, pipe taps and dies, reamer, joint compound, etc.
PFI	Industrial pipe fitter's tools: hex wrenches, drills, taps and dies, tubing tools, screwdrivers, gasket cutters, plus all PF tools
IR	Instrument repair tools and shop facilities
SM	Sheet metal working tools and equipment: snips, shears, drill, break, etc.
MAC	Machine shop
W	Welding equipment (portable electric arc type)
AS	General auto shop tools and equipment
E	Electrician's tools (industrial type): tools for thinwall and rigid conduit, pulling tape, small hand tools, etc.
EX	Heavy-duty electrician's tools: tools for high-voltage cable and large conduit
C	Carpenter's tools
H	Hoisting equipment - light (up to 2000 lb)
HX	Hoisting equipment - heavy (up to 50 tons)

Supplies

SP	Small pipe and fittings (2 in. and smaller)
LP	Large pipe and fittings (4 in. and larger), grade A-53 and welding fittings
G	Gasket sets, gasket material, seals, packing, etc.
E	600-volt wire in various sizes plus conduit to 2 in. with fittings
EX	High-voltage wire plus conduit over 2 in. with fittings
LM	Lumber

Labor Skills

P	Plumber - able to measure, cut, thread, and assemble pipe with usual fittings and values
PFW	Pipe fitting welder - same skills as P with added skill of pipe welding, either electric or gas
PF	Pipe fitter - same skills as P but with additional experience in working with large pipe, flanged joints, connecting instruments
IR	Instrument repairman - experience in shop repair, overhaul, and maintenance of controls, regulators, power-operated valves, etc.
L	Laborer or unskilled helper
E	Journeyman electrician

<u>Labor Skills</u>, Cont.

C	Journeyman carpenter
M	Millwright or mechanic
MAC	Machinist
OP	Operating engineer
SM	Sheet metal worker
H	Handyman - general tool use capability but not journeyman quality in any one trade
AM	Auto mechanic

G-1a FIRST STAGE PRESSURE REGULATOR (VALVE)
CITY GATE STATION

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	1-2 psi Control and instrument piping leaks due to cracks and/or broken joints	TOTAL TIME (hours)	2.5		1.0	5.0		2.0
		EFFORT (man hours)	5.0		2.0	10.0		4.0
		EQUIPMENT	PFI		PFI	PF		PF
		SUPPLIES	SP		SP	SP		SP
		SPARE PARTS						
		LABOR SKILLS (man hours)	2.5 PFI, 2.5 PF		1 PFI, 1 PF	5 H, 5 L		2 H, 2 L
		SHOP FACILITIES						
		REMARKS		Same as LIGHT IA	Gas output 100%, leaks not fully repaired		Same as LIGHT II A	Gas output 100%, leaks not fully repaired
MODERATE DAMAGE	4 psi Control and instrument piping severly damaged; replacement or major repair is necessary	TOTAL TIME (hours)	11		10	28		15
		EFFORT (man hours)	11		20	10		30
		EQUIPMENT	PFI		PFI, H	PF		PF, H
		SUPPLIES	SP		SP, valves, gages			SP, valves, gages
		SPARE PARTS	Yes		Assumed	Yes		Assumed
		LABOR SKILLS (man hours)	7 PFI, 4 IR		10 PFI, 10 MW	2 H, 12 L, 14 AM		15 H, 15 L
		SHOP FACILITIES	1R		Assumed	AS		Assumed
		REMARKS		Same as Moderate IA	Manually operated valves and pressure gage substituted for regulator Gas output 100%, but poorer control and more personnel required.		Same as Moderate II A	Manually operated valves and pressure gage substituted for regulator Gas output 100%, but poorer control and more personnel required.
SEVERE DAMAGE	5-10 psi Valve body and/or actuating mechanism is severly damaged. Cases are cracked and/or distorted. Shafts and linkages are bent and jammed.	TOTAL TIME (hours)	16			36		
		EFFORT (man hours)	28			52		
		EQUIPMENT	PFI, H			PF, H		
		SUPPLIES	SP, G			SP, G		
		SPARE PARTS	Yes			Yes		
		LABOR SKILLS (man hours)	8 PF, 8 PFI, 12 IR			16 PF, 20 AM, 16 I		
		SHOP FACILITIES	1R			1R		
		REMARKS		Same as SEVERE I A	Same as Moderate I C		Same as SEVERE II A	Same as MODERATE II C

G-1b FIRST STAGE PRESSURE REGULATOR (COMPRESSED AIR SUPPLY) CITY GATE STATION

ASSUME ELECTRIC MOTOR DRIVEN AIR COMPRESSOR MOUNTED ABOVE GROUND IN PREFAB STEEL INDUSTRIAL BUILDING. PIPING ASSUMED TO BE ATTACHED TO BUILDING.

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	1-1½ psi Electrical controls and wiring damaged Small piping damaged as parts of building siding and roofing deflect	TOTAL TIME (hours)	16	12	8	24	18	16
		EFFORT (man hours)	48	36	24	72	54	48
		EQUIPMENT	PF-E	PF-E	PF-E	PF-E	PF-E	PF-E
		SUPPLIES	SP-E	SP-E	SP-E	SP-E	SP-E	SP-E
		SPARE PARTS						
		LABOR SKILLS (man hours)	16 PF, 16 E, 16 L	12 PF, 12 E, 12 L	8 PF, 8 E, 8 L	48 H, 24 L	36 H, 18 L	32 H, 16 L
		SHOP FACILITIES						
		REMARKS Building repair not included Electrical controls and wiring assumed to be field repairable.			100% air output			100% air output
MODERATE DAMAGE	2-4 psi Electrical control and wiring and small piping severely damaged Some missile damage to exterior of compressor but field repairable Building virtually destroyed	TOTAL TIME (hours)	24	18	16	48	36	32
		EFFORT (man hours)	72	54	48	144	108	96
		EQUIPMENT	PF-E	PF-E	PF-E	PF-E	PF, E	PF-E
		SUPPLIES	SP-E	SP-E	SP-E	SP-E	SP, E	SP-E
		SPARE PARTS	Yes	Yes	Yes	Yes	Yes	Yes
		LABOR SKILLS (man hours)	24 PF, 24 E, 24 L	18 PF, 18 E, 18 L	16 PF, 16 E, 16 L	96 H, 48 L	72 H, 36 L	64 H, 32 L
		SHOP FACILITIES						
		REMARKS Building repair not included Electrical controls and wiring assumed to require replacement rather than repair Some structure built to support wiring and piping			Air output 100% but quality of air degraded due to lack of system refinements			Air output 100% but quality of air degraded due to lack of system refinements.
SEVERE DAMAGE	5-6 psi Entire air compressor system damaged beyond repair	TOTAL TIME (hours)	24		16	48		24
		EFFORT (man hours)	96		16	192		48
		EQUIPMENT	PF-E		IR	PF-E		IR
		SUPPLIES	SP-E		IR-SP	SP-		IR, SP
		SPARE PARTS	complete		Pilot regulator	complete		Pilot regulator
		LABOR SKILLS (man hours)	40 PF, 32 E, 24 L		16 IR	80 PF, 64 E, 48 L		24 H, 24 AM
		SHOP FACILITIES			IR			AR
		REMARKS Building repair not included	Replacement with factory package unit	Same as SEVERE I A	Abandon compressed air system. Convert valve to gas operation 75% effective	Replacement with factory package system	Same as SEVERE II A.	Abandon compressed air system. Convert valve to gas operation 75% effective

G-2 SECOND STAGE PRESSURE REGULATOR
CITY GATE STATION

ASSUMES GAS OPERATED PILOT CONTROLLED VALVE (FISHER MODEL [illegible]) IS TYPICAL [illegible] FREE STANDING ABOVE GROUND IN VALVE YARD

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS						
MODERATE DAMAGE	2 psi Small external piping and components broken loose and leaking	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	2.0 4.0 PF SP 2 PF, 2 L	Same as MODERATE I A	1.0 2.0 PF SP 1 PF, 1 L Gas output 100% but leaks not fully repaired	3.0 6.0 PF SP 3 H, 3 L	Same as MODERATE II A	2.0 4.0 PF SP 2 H, 2 L Gas output 100% but leaks not fully repaired
SEVERE DAMAGE	6-8 psi Small pipe and components damaged Valve itself severely damaged	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	10 16 PFI · H SP · G Yes 6 PFI, 6 L, 4 IR, 3 R Field repair not feasible, valve must be removed for shop repair	Same as SEVERE I A	8 16 PFI · H · W SP · O · Valves Not Available 8 PFW, 8 PFI Manually-operated valves and pressure gage substituted for regulator. Gas output 100%, but poorer control and more personnel required	20 30 PFI · H SP · G Yes 10 H, 10 L, 10 AM, AS Field repair not feasible, valve must be removed for shop repair	Same as SEVERE II A	16 32 PFI · H · W SP, G Not available 16 H, 16 AM M[illegible]lly operated valve[illegible] are [illegible] ge [illegible] for regula[illegible] [illegible]put [illegible]00%, [illegible] poorer control an[illegible] more personnel required

G-3 ORIFICE - TYPE FLOWMETER
CITY GATE STATION

ASSUMES ORIFICE, ORIFICE METERING UNIT, READOUT RECORDER AND ALL CONNECTING PIPING (AMERICAN METER ASSEMBLY) IS MOUNTED FREE STANDING, ABOVE GROUND IN VALVE YARD

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	2 psi Readout instrumentation and recorder lightly damaged but incapable of measuring or indicating flow	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS Damage is assumed to be field repairable	2 4 PF IR SP yes 2PF 2IR	Same as LIGHT IA	Same as LIGHT IA	4 8 PF SP Entire Unit 4H, 4L Unskilled workers could not repair the instruments but could replace them	Same as LIGHT IIA	Same as LIGHT IIA
MODERATE DAMAGE	4 psi Small connecting piping damaged and leaking Recorder is moderately damaged	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS Piping assumed field repairable, recorder shop repairable	11 14 PF IR SP yes 1 PF, 1 L, 2 PFI, 10 IR	Same as MODERATE IA	Same as MODERATE IA	6 12 PF SP Entire Unit 6H, 6L Unskilled workers could not repair the instruments but could replace them	Same as MODERATE IIA	Same as Moderate IIA
SEVERE DAMAGE	15 psi Recorder and small connecting piping are a total loss Broken tap connections and damage at the orifice itself causing leaking	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	4 8 PF SP Entire unit 1 PF, 1 L, 3 PFI, 3IR Does not include any replacement of shelter or long leads to or from instrument	Same as SEVERE IA	2 4 PF SP Assumed 2PF, 2L Measurement function is lost. Gas output could still be 100% after stopping leaks	8 16 PF SP Entire Unit 8H, 8L Does not include any replacement of shelter or long leads to or from instrument	Same as SEVERE IIA	3 6 PF SP Assumed 3H, 3L Measurement function is lost. Gas output could still be 100% after stopping leaks

G-4 ODORIZATION FACILITIES
CITY GATE STATION

ASSUMED INJECTION-TYPE ODORIZER PACKAGE UNIT (PROBLEMS UP TO TYPICAL) IS LOCATED ABOVE GROUND IN A SMALL PREFAB-TYPE SHED IN THE VALVE YARD. PIPING IS ATTACHED DIRECTLY TO THE SHED ITSELF

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	1-2 psi Extensive deformation of building. Some minor damage to building - supported piping.	TOTAL TIME (hours) EFFORT (manhours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (manhours) SHOP FACILITIES REMARKS	8 24 SM, PF SP - Sheet metal 8 SM, 8 PF, 8L Building not repaired to original condition. Holes patched; dents straightened; piping repaired.	8 16 PF SP 8 PF, 8L Building not repaired, only pipe damage repaired.	Same as LIGHT IB	12 36 SM, PF SP - Sheet metal Building not repaired to original condition. Holes patched; dents straightened; piping repaired.	12 24 PF SP Building not repaired; only pipe damage repaired.	Same as LIGHT IIB
MODERATE DAMAGE	2-3 psi Building overturned and crushed. Pipe connections to main broken. Extensive damage to small piping.	TOTAL TIME (hours) EFFORT (manhours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	56 112 C, SM, PF LM, Concrete, SP 6'×10' Prefab steel bldg. 32 L, 16C, 32 SM, 16 PF1, 16 PF Original building cut away. Spilled odorant cleaned up. Building replaced with concrete slab and prefab steel building. Small piping repaired.	72 144 C, PF LM, Concrete, SP 32L, 89C, 16 PF1, 16 PF Original building cut away. Spilled odorant cleaned up. Building replaced with concrete slab and wooden shed. Small piping repaired.	24 64 PF SP 32 L, 16 PF1, 16 PF No replacement of building; only debris clearance. Odorizer repaired and modified for outdoor operation.	84 168 C, SM, PF LM, Concrete, SP 6'×10' prefab steel bldg. Original building cut away. Spilled odorant cleaned up. Building replaced with concrete slab and prefab steel building. Small piping repaired.	108 216 C, PF LM, Concrete, SP Original building cut away. Spilled odorant cleaned up. Building replaced with concrete slab and wooden shed. Small piping repaired.	36 96 PF SP No replacement of building; only debris clearance. Odorizer repaired and modified for outdoor operation.
SEVERE DAMAGE	3-4 psi Building destroyed, contents and small piping severely damaged. Odorizer tanks intact but deformed and bent on supports. Sep. pump and drive-motor slightly damaged.	TOTAL TIME (hours) EFFORT (manhours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (manhours) SHOP FACILITIES REMARKS	80 152 C, SM, PF, W LM, Concrete, SP Sight glass, meter, pump, valves Same as MODERATE IA plus: Drain and disassemble odorizer. Straighten, repair, and reassemble	88 184 C, PF, W LM, Concrete, SP Sight glass, meter, pump, valves Same as MODERATE IB plus: Drain and disassemble odorizer. Straighten, repair, and reassemble.	40 104 PF, W SP Sight glass, meter, pump, valves Same as MODERATE IC.	120 228 C, SM, PF, W LM, Concrete, SP Sight glass, meter, pump, valves Same as SEVERE IA.	132 276 C, PF, W LM, Concrete, SP Sight glass, meter, pump, valves Same as SEVERE IB.	60 156 PF, W SP Sight glass, meter, pump, valves Same as SEVERE IC.

G-6 FIRST STAGE RELIEF VALVE
CITY GATE STATION

[illegible]

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	Total time (hours) Effort (man hours) Equipment Supplies Spare parts Labor skills (man hours) Shop facilities Remarks						
MODERATE DAMAGE	No moderate level damage predicted	Total time (hours) Effort (man hours) Equipment Supplies Spare parts Labor skills (man hours) Shop facilities Remarks						
SEVERE DAMAGE	2 10 psi Valve body and mechanism housing cracked or distorted causing leaks and making further operation unsafe	Total time (hours) Effort (man hours) Equipment Supplies Spare parts Labor skills (man hours) Shop facilities Remarks	1.0 2.0 PFI G Replacement Valve 1 PFI, 1 L Repair not feasible, replacement required	Same as SEVERE I A	2.0 4.0 PFI .3P G Rupture Disc or Valve Not available 2 PFI, 2 L Valve replaced with rupture disc or manual valve and pressure gage Gas output 100%, but less reliable	1.5 3 PFI G Replacement Valve — Repair not feasible, replacement required	Same as SEVERE II A	3.0 6.0 PFI .3P G Rupture Disc or Valve Not available 3 H, 3 L Valve replaced with rupture disc or manual valve and pressure gage Gas output 100%, but less reliable

G-7 SECOND STAGE RELIEF VALVE
CITY GATE STATION

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS						
MODERATE DAMAGE	3 psi Small external piping and components broken loose and leaking	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	2.0 4.0 PF SP 2 PF, 2 L	Same as MODERATE I A	1.0 2.0 PF SP 2 PF Gas output 100%, but leaks are not fully repaired	3.0 6.0 PF SP 3 H, 3 L	Same as MODERATE II A	1.5 3.0 PF SF 1.5 H, 1.5 L Gas output 100% but leaks are not fully repaired
SEVERE DAMAGE	6-8 psi Small pipe and components damaged Valve itself damaged	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	8.0 12.0 PFI-H SP-G Yes 4 PFI, 4 L, 4 IR IR Field repair not feasible, valve must be removed for shop repair	Same as SEVERE I A	6.0 12.0 PFI-H SP-G Rupture Disc or Valve Not Available 6 PFI, 6 L Valve replaced with rupture disc or manual valve and pressure gage Gas output 100% but less reliable	18 24 PFI-H SP-G Yes 8 H, 8 L, 10 AM AS Field repair not feasible, valve must be removed for shop repair	Same as SEVERE II A	8 16 PFI-H SP-G Rupture Disc or Valve Not Available 8 H, 8 L Valve replaced with rupture disc or manual valve and pressure gage Gas output 100% but less reliable

(G-8) OFFICE, DISPATCH, and CONTROL BUILDING
CITY GATE STATION

ASSUMES THAT THE BUILDING IS A MODULAR PREFAB STEEL INDUSTRIAL BUILDING (SHEET METAL SIDING AND SEPARATE STRUCTURAL STEEL FRAMEWORK)

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	1½ psi 50% of roofing and siding panels are damaged or missing	TOTAL TIME (hours) EFFORT (manhours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS	The prefab nature of the building makes repair to condition "A" impossible without full availability of factory-supplied parts	12 36 Crane Fasteners, sheet metal, etc. Clips, etc Steelworkers Repair roofing and siding Replace paneling with sheet metal where necessary	12 36 Crane Fasteners, paneling, etc. Carpenters Replace damaged or missing panels with any type of exterior-duty paneling (plywood corrugated steel, etc)	Same as LIGHT IA	24 72 Crane Fasteners, sheet metal, etc Clips, etc Steelworkers Repair roofing and siding Replace paneling with sheet metal where necessary	24 72 Crane Fasteners, paneling, etc. Carpenters Replace damaged or missing panels with any type of exterior duty paneling (plywood, corrugated steel etc)
MODERATE DAMAGE	2½ psi All roofing and siding stripped off Steel frame distorted	TOTAL TIME (hours) EFFORT (manhours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS	Same as LIGHT IA	40 160 Crane, cutting & welding equip Fasteners, sheet metal Steelworkers Straighten and repair damaged frame Replace damaged or missing paneling	Same as MODERATE IB	Same as LIGHT IA	80 320 Crane, cutting & welding equip Fasteners, sheet metal Steelworkers Straighten and repair damaged frame Replace damaged or missing paneling	Same as MODERATE IIB
SEVERE DAMAGE	6 psi Building virtually destroyed Only the foundation is intact No building components are salvageable for reuse	TOTAL TIME (hours) EFFORT (manhours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS	Same as LIGHT IA	50 250 Crane Steelworkers Erect a new building of similar design on the foundation Above estimate does not include the time or other resources required for shop prefabrication	Build a suitable sheltering structure out of available materials No time estimate is possible		100 500 Crane Steelworkers Erect a new building of similar design on the existing foundation Above estimate does not include the time or other resources required for shop prefabrication	Same as SEVERE IIB

G-12a LP GAS STORAGE TANKS
LP-AIR PEAK-SHAVE PLANT

ASSUMES STANDARD 30,000 GAL STEEL LP GAS TANKS MOUNTED ABOVE GROUND ON STEEL OR CONCRETE SADDLES

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	.3 psi Relief valve vent pipes for loose and carried away Stress damages relief valve	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS, LABOR SKILLS (man hours) SHOP FACILITIES REMARKS Assume very little LP gas escapes. Remainder of tank contents is available to substitute for gas	3 6 PF1 SP, G Relief valve, vent pipe 3 PF1, 3L Replace valve and vent pipes	Same as LIGHT IA	3 6 PF1 SP, G Rupture disc assy 3PF1, 3L Substitute rupture disc for relief valve 100% functional but requires more attention	5 10 PF1 SP, G Relief valve, vent 5H, 5L Replace valve and vent pipes	Same as LIGHT IIA	5 10 PF1 SP, G Rupture disc assy 5H, 5L Substitute rupture disc for relief valve 100% functional but requires more attention
MODERATE DAMAGE	9 psi Fill and draw piping to tank is damaged and leaking	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS No repairs would be attempted if the tank were empty or if the vaporizer-mixer unit could not be repaired	Repair to condition "A" is not possible since this would require welding all joints. Welding would require emptying and purging the tank. There is no simple way to do this without losing the gas itself	12 24 PF1 SP 12 PF1, 12 PF Replace relief valve and vents. Repair fill and draw piping using threaded pipe fittings where necessary to avoid welding	8 16 PF1 SP 8 PF1, 8 PF Substitute rupture disc for relief valve. Repair fill and draw piping using threaded pipe fittings where necessary to avoid welding. 100% functional but requires more attention	Same as MODERATE IA	18 36 PF1 ?? 18H, 18L Replace relief valve and vents. Repair fill and draw piping using threaded pipe fittings where necessary to avoid welding	Substitute rupture disc for relief valve. Repair fill and draw piping using threaded pipe fittings where necessary to avoid welding. 100% functional but requires more attention
SEVERE DAMAGE	D = 9 psi Tank is displaced from mounting saddles with all connecting piping severely damaged	TOTAL TIME EFFORT EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS Tank would have to be drained to be placed back in service. System is of no value as a postattack gas source						

G-12b VAPORIZER - MIXER UNIT LP-AIR PEAK-SHAVE PLANT

ASSUMES VAPORIZER MIXER UNIT 125,000 CFH DIRECT-FIRED ALGAS IS TYPICAL [illegible] MOUNTED FREE STANDING ABOVE GROUND IN VALVE YARD OF PEAK SHAVE INSTALLATION

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	1 psi Sheet metal cabinet doors, door latches, and vent damaged	Total time (hours) Effort (manhours) Equipment Supplies Spare parts Labor skills (manhours) Shop facilities Remarks	8 16 Doors, latches, vent 8W, 8 SM Replace with new factory supplied parts	10 30 W, SM Sheet metal Latches, vent 10W, 20 SM Replace parts with shop or field fabricated substitutes	4 4 4 SM Straighten out doors so they can be closed Fabricate makeshift latches and vent Gas output 100%	10 20 Doors, latches, vent 20 AM Replace damaged parts with factory supplied parts	15 30 W, SM Sheet metal Latches, vent 30 AM Replace damaged parts with shop or field fabricated substitutes	5 5 5 AM Straighten out doors so they can be closed Fabricate makeshift latches and vent Gas output 100%
MODERATE DAMAGE	3 psi Sheet metal cabinet severely damaged but still intact. Small internal components attached to the cabinet are leaking gas. Sheet metal vaporizing columns are dented but repairable	Total time (hours) Effort (manhours) Equipment Supplies Spare parts Labor skills (manhours) Shop facilities Remarks Repairs would not be attempted if LP storage tanks were empty	24 48 PF New cabinet, gaskets 8W, 8 SM, 32 PF Replace damaged parts with new, factory supplied parts	32 62 W, SM, PF Sheet metal, tubing, fittings Latches, vent, gaskets 10W, 20 SM, 32 PF Replace damaged parts with shop or field fabricated substitutes Repair components where possible	32 38 W, SM, PF Tubing, fittings, etc. gaskets 2W, 4 SM, 32 PF Perform makeshift repairs on cabinet and internal components Straighten out columns Gas output approx 60% design rate	30 60 PF New cabinet, gaskets 60 AM Replace with new factory supplied parts	45 90 W, SM Sheet metal, tubing, fittings Latches, vent, gaskets 90 AM Replace damaged parts with shop or field fabricated substitutes Repair components where possible	50 100 W, SM, PF Tubing, fittings, etc. gaskets 100 AM Perform makeshift repairs on cabinet and internal components Straighten-out columns Gas output approx 60% design rate
SEVERE DAMAGE	5 psi Cabinet torn from base. Virtually all internal components severely damaged (venturi and check valve are still functional)	Total time (hours) Effort (manhours) Equipment Supplies Spare parts Labor skills (manhours) Shop facilities Remarks	The peak shave facility is too severely damaged to deliver gas in the immediate postattack period. Repair or replacement is possible but not in time to be of any value	Same as SEVERE IA	Same as SEVERE IA	Same as SEVERE IA	Same as SEVERE IA	Same as SEVERE IA

G-12c SURGE TANK (LP-AIR MIXTURE)
LP-AIR PEAK-SHAVE PLANT

ASSUMES HORIZONTAL, CYLINDRICAL, STEEL SURGE TANK (~ 30' x 8' DIA) FIXED RIGIDLY TO SADDLES

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	3 psi Relief valve damaged vent pipe carried away	TOTAL TIME (hours) EFFORT (man-hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man-hours) SHOP FACILITIES REMARKS	3.0 6.0 PFI SP, G Relief valve, vent 3 PFI, 3L Replace valve and vent pipe (s)	Same as LIGHT IA	3.0 6.0 PFI SP, G Not available 3 PFI, 3L Replace valve with rupture disc 100% functional	5 10 PFI SP, G Relief valve 5H, 5L Replace valve and vent pipe(s)	Same as LIGHT IIA	5 10 PFI SP, G Not available 5H, 5L Replace valve with rupture disc 100% functional
MODERATE DAMAGE	5 psi Minor displacement of connecting piping causes leaks at tank inlets and outlets	TOTAL TIME (hours) EFFORT (man-hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man-hours) SHOP FACILITIES REMARKS	8 16 PFI, W SP, G Relief valve 8 PFW, 8L Replace relief valve and vent pipes Repair damaged piping and tank connections	Same as MODERATE IA	8 16 PFI, W SP, G Not available 8 PFW, 8L Replace relief valve with rupture disc Repair damaged piping and tank connections 100% functional	12 24 PFI, W SP, G Relief valve 8H, 8L, 8 general welder Replace relief valve and vent pipes Repair damaged piping and tank connections	Same as MODERATE IIA	12 24 PFI, W SP, G Not available 8H, 8L, 8 general welder Replace relief valve with rupture disc Repair damaged piping and tank connections 100% functional
SEVERE DAMAGE	6-8 psi Severe damage to tank inlet and outlet connections Considerable gas leakage Tank still remains on its saddle	TOTAL TIME (hours) EFFORT (man-hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man-hours) SHOP FACILITIES REMARKS No repair would be attempted if the LP storage tanks were empty or if the vaporizer-mixer could not be repaired	Replace tank with new one Repair damaged piping	Vent and purge tank Field repair broken fittings and damaged piping	Bypass surge tank by connecting vaporizer outlet line directly into distribution main 60 → 100% functional	Same as SEVERE IA	Same as SEVERE IB	Same as SEVERE IC

G-13a SERVICE REGULATOR DISTRIBUTION SYSTEM (DOMESTIC AND COMMERCIAL CONSUMERS)

ASSUMES REGULATOR (ROCKWELL 143 TO 243 ARE TYPICAL) IS AT GROUND LEVEL DIRECTLY ALONGSIDE BUILDING. INLET PIPE EMERGES DIRECTLY FROM GROUND, OUTLET CONNECTED DIRECTLY TO METER THEN ENTERS BUILDING

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS						
MODERATE DAMAGE	No moderate level damage predicted	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS						
SEVERE DAMAGE	25 psi Case damaged but repairable	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	FIELD / SHOP 1/2 / 10 1/2 / 10 PF / IR — / — unit from stock / yes 1/2 PF / 10 IR — / IR Regulator replaced by an operable unit from stock, repaired in the shop, then used to replace another damaged unit	Same as SEVERE I A This is a go no go situation	Same as SEVERE I A This is a go no go situation	FIELD / SHOP 1/2 / 2.0 3/4 / 2.0 PF / IR — / — unit from stock / Yes 1/2 H / 10 AM — / IR Regulator replaced by an operable unit from stock, repaired in the shop, then used to replace another damaged unit	Same as SEVERE II A This is a go-no go situation	Same as SEVERE II A This is a go-no go situation

G-13b SERVICE REGULATOR DISTRIBUTION SYSTEM (INDUSTRIAL CONSUMER)

ASSUMES REGULATOR IS GAS OPERATED, PILOT TYPE (FISHER 290 TYPICAL) VALVE IS MOUNTED FREE-STANDING, ABOVE GROUND IN A SMALL, OUTDOOR CONTROL COMPLEX

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS						
MODERATE DAMAGE	5 psi Small external piping and components broken loose and leaking.	TOTAL TIME (hours)	2.0		1.0	3.0		2.0
		EFFORT (man hours)	4.0		2.0	6.0		4.0
		EQUIPMENT	PF		PF	PF		PF
		SUPPLIES	SP		SP	SP		SP
		SPARE PARTS						
		LABOR SKILLS (man hours)	2 PF, 2 L		1 PF, 1 L	3 H, 3 L		2 H, 2 L
		SHOP FACILITIES						
		REMARKS		Same as MODERATE IA	Gas output 100% but leaks not fully repaired.		Same as MODERATE IIA	Gas output 100% but leaks not fully repaired.
SEVERE DAMAGE	8-10 psi Small pipe and component damaged. Valve itself severely damaged.	TOTAL TIME (hours)	10		8	20		16
		EFFORT (man hours)	16		16	30		32
		EQUIPMENT	PFI-H		PFI-H-W	PFI-H		PFI-H-W
		SUPPLIES	SP-G		SP-G-Valves	SP-G		SP-G
		SPARE PARTS	Yes		Not Available	Yes		not available
		LABOR SKILLS (man hours)	6 PFI, 6 L, 4 IR 2 R		8 PFW, 8 PFI	10 H, 10 L, 10 AM 15		16 H, 16 AM
		SHOP FACILITIES						
		REMARKS	Field repair not feasible, valve must be removed for shop repair.	Same as SEVERE IA	Manually-operated valves and pressure gage substituted for regulator. Gas output 100%, but poorer control and more personnel required.	Field repair not feasible; valve must be removed for shop repair.	Same as SEVERE IIA	Manually-operated valves and pressure gage substituted for regulator. Gas output 100%, but poorer control and more personnel required.

G-14a SERVICE METER
DISTRIBUTION SYSTEM (DOMESTIC CONSUMER)

ASSUMED METER (AMERICAN AL 275-N ARE TYPICAL) IS AT GROUND LEVEL DIRECTLY ALONGSIDE HOUSE. INLET PIPE EMERGES DIRECTLY FROM GROUND (PERHAPS VIA REGULATOR). OUTLET PIPE ENTERS HOUSE DIRECTLY

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	Total time (hours) Effort (man hours) Equipment Supplies Spare parts Labor skills (man hours) Shop facilities Remarks						
MODERATE DAMAGE	No moderate level damage predicted	Total time (hours) Effort (man hours) Equipment Supplies Spare parts Labor skills (man hours) Shop facilities Remarks						
SEVERE DAMAGE	75 psi Meter case is broken and unit is inoperable	Total time (hours) Effort (man hours) Equipment Supplies Spare parts Labor skills (man hours) Shop facilities Remarks	Field / Shop 1/4 / 1.0 1/2 / 1.0 PF / IR —— / —— meter fr stck / Yes 1/2 PF / 1.0 IR IR Meter replaced by an operable unit from stock, repaired in the shop, then used to replace another damaged unit	Same as SEVERE IA	1.0 1.0 PF SP Not Available 1.0 PF —— Meter replaced with jumper output 100% but no measurement	Field / Shop 1.5 / 2.0 1.5 / 2.0 PF / IR —— / —— meter from stock / Yes 1.5 H / 2.0 AM —— / 1 R Meter replaced by an operable unit from stock, repaired in the shop, then used to replace another damaged unit	Same as SEVERE II A	2.0 2.0 PF SP Not available 2.0 H —— Meter replaced with jumper Gas output 100% but no measurement.

G-14b SERVICE METER DISTRIBUTION SYSTEM (COMMERCIAL CONSUMER)

ASSUMES METER (AMERICAN 250 B IS TYPICAL) IS ATTACHED TO THE SERVICE REGULATOR AND THAT BOTH ARE LOCATED AT GROUND LEVEL DIRECTLY ALONGSIDE A BUILDING. PIPE ENTERS BUILDING AT THE METER LOCATION

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	TOTAL TIME EFFORT EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS						
MODERATE DAMAGE	No moderate level damage predicted	TOTAL TIME EFFORT EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS						
SEVERE DAMAGE	≥5 psi Meter case is broken and unit is inoperable	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	8.0 12 PF - IR - H — Yes 4 PF, 4 L, 4 IR IR Meter replaced by an operable unit from stock, repaired in shop, then used to replace another damaged unit	Same as SEVERE IA	2.0 4.0 PF - H SP Not Available 2 PF, 2 L Meter replaced with jumper Gas output 100%, but no measurement	12 20 PF - IR - H — Yes 6 H, 6 L, 8 AM IR Meter replaced by an operable unit from stock, repaired in shop, then used to replace another damaged unit.	Same as SEVERE IIA	3.0 6.0 PF - H SP Not available 3 H, 3 L Meter replaced with jumper Gas output 100%, but no measurement

G-14c SERVICE METER (BELLOWS-TYPE)
DISTRIBUTION SYSTEM (INDUSTRIAL CONSUMER)

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	TOTAL TIME EFFORT EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS						
MODERATE DAMAGE	No moderate level damage predicted	TOTAL TIME EFFORT EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS						
SEVERE DAMAGE	8 psi Meter case broken and unit inoperable	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	8 12 PFI H G Yes 4 PFI, 4L, 4IR IR Meter replaced by an operable unit from stock, repaired in shop, then used to replace another damaged unit	Same as SEVERE I A	4 8 PFI H W LP Not Available 4 PFW 4L Meter replaced with a jumper Gas output 100% but no measurement	16 22 PFI H G Yes 6 H, 6 L, 10 AM IR Meter replaced by an operable unit from stock, repaired in shop, then used to replace another damaged unit	Same as SEVERE II A	8 16 PFI-H-W LP Not Available 8 H, 4L, 4 Welder Meter replaced with a jumper Gas output 100% but no measurement

G-14d SERVICE METER (ROOTS - TYPE)
DISTRIBUTION SYSTEM (INDUSTRIAL CONSUMER)

[illegible]

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	2 psi Dials broken and glass sight tubes for oil level broken (If allowed to operate very long before repair, the lack of lubricating oil would lead to serious damage to gears and bearings)	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	2.0 2.0 PF SP Yes 2 PF Replace broken parts	Same as LIGHT IA	1.0 1.0 PF SP Not Available 1 PF Remove broken parts and plug Gas output 100%	3.0 3.0 PF SP Yes 3 H Replace broken parts.	Same as LIGHT IIA	15 15 PF SP Not Available. 15 H Remove broken parts and plug Gas output 100%
MODERATE DAMAGE	No moderate level damage predicted	TOTAL TIME EFFORT EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS	Same as LIGHT IA	Same as LIGHT IA	Same as LIGHT IC	Same as LIGHT IIA	Same as LIGHT IIA	Same as LIGHT IIC
SEVERE DAMAGE	4 psi Glass sight tubes broken for oil level Case cracked from strain exerted by connecting pipe	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	12 16 PFI-H G Yes 4 PFI, 4 L, 8 IR IR Meter replaced by an operable unit from stock, repaired in shop, then used to replace another damaged unit	Same as SEVERE IA	4 8 PFI-H-W LP Not Available 4 PF W, 4 L Meter replaced by a jumper. Gas output 100%, but no measurement	16 22 PFI H G Yes 8 H, 8 L, MIAM IR Meter replaced by an operable unit from stock, repaired in shop, then used to replace another damaged unit	Same as SEVERE IIA	8 16 PFI-H-W LP Not available. 4 L, 8 H, 5 Welder Meter replaced by a jumper. Gas output 100% but no measurement

G-15 STRAINER

DISTRICT REGULATOR INSTALLATION

[illegible]

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	... 1 psi Filter elements clogged by dirt Shaken loose by blast	Total time (hours) Effort (man hours) Equipment Supplies Spare parts Labor skills (man hours) Shop facilities Remarks	.5 .5 PI — Filter Elements .5 PI Replace Filter Elements	1.5 1.5 PI Solvent Not Available 1.5 PI Clean existing Filter Elements	.5 .5 PI — Not Available .5 PI Remove elements but don't replace (gas output 100% but increased danger of valve clogging and damaging downstream components	.5 .5 PF — Filter Elements 3 L Replace Filter elements	.5 1.5 PF Solvent Not Available 1.5 L Clean existing Filter Elements	.5 .5 PF — Not Available .5 L Remove elements but don't replace (gas output 100% but increased danger of valve clogging and damaging downstream components
MODERATE DAMAGE	No moderate level damage predicted	Total time Effort Equipment Supplies Spare parts Labor skills Shop facilities Remarks	Same as LIGHT IA	Same as LIGHT IB	Same as LIGHT IC	Same as LIGHT IIA	Same as LIGHT IIB	Same as LIGHT IIC
SEVERE DAMAGE	> 10... psi Strainer body damaged beyond repair	Total time (hours) Effort (man hours) Equipment Supplies Spare parts Labor skills (man hours) Shop facilities Remarks	1.5 3.0 PFI G Complete unit 1.5 PF, 1.5 L Replace with new strainer assembly	Same as SEVERE IA	3.0 6.0 PFI - W LP - G Not Available 3 PF W, 3 L Replace strainer assembly with spool (gas output 100% but increased danger of clogging and damaging downstream components	3.0 6.0 PFI G Complete unit 3 H, 3 L Replace with new strainer assembly	Same as SEVERE IIA	6.0 12.0 PFI - W LP - G Not Available 6 H, 6 General Welder Replace strainer assembly with spool (gas output 100% but increased danger of clogging and downstream components

G-16 PRESSURE REGULATOR
DISTRICT REGULATOR INSTALLATION

ASSUMED VALVE IS GAS OPERATED, PILOT TYPE (FISHER 99 TYPICAL). INSTALLATION IS BELOW GRADE IN CONCRETE VAULT COVERED WITH STEEL PLATE DOORS. THIS IS TYPICAL FOR ALL RANGES OF PRESSURE CUTS (HIGH TO INTER., HIGH TO LOW & INTER. TO LOW)

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted	TOTAL TIME EFFORT EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS						
MODERATE DAMAGE	3 psi Impact of steel vault doors damages small piping and ancillary components	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	2.0 4.0 PF SP 2 PF, 2L	Same as MODERATE IA	1.0 2.0 PF SP 1PF, 1L Gas output 100% but not all gas leaks are controlled	3.0 6.0 PF SP 3H, 3L	Same as MODERATE IIA	2.0 4.0 PF SP 2H, 2L Gas output 100% but not all gas leaks are controlled
SEVERE DAMAGE	5 psi Impact of steel vault doors damages regulator valve itself. Valve body and topworks deformed and leaking	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	10 16 PFI, H SP, G 6PFI, 6L, 4IR IR Field repair not feasible. Valve must be removed for shop repair	Same as SEVERE IA	8 16 PFI, H, W SP, G, valves, press gage 8 PFW, 8 PFI Manually-operated valves and pressure gage are substituted for regulator. Gas output 100%, but poorer pressure control and increased attention required	20 30 PFI, H SP, G 10H, 10L, 10 AM AS Field repair not feasible. Valve must be removed for shop repair	Same as SEVERE IIA	16 32 PFI, H, W SP, G, valves, press gage 16H, 16L Manually operated valves and pressure gage are substituted for regulator. Gas output 100%, but poorer pressure control and increased attention required

G-17 RELIEF VALVE
DISTRICT REGULATOR INSTALLATION

ASSUMES THAT VALVE IS MOUNTED BELOW GROUND IN A CONCRETE VAULT COVERED BY STEEL PLATE DOORS. VALVE IS RIGIDLY CONNECTED TO PIPE WHICH LEAVES THROUGH VAULT

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	No light level damage predicted.	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS						
MODERATE DAMAGE	3 psi Small external piping and components broken loose and leaking Damage results from impact by steel doors of vault	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	2.0 4.0 PF SP 2 PF, 2 L	Same as Moderate I A	1.0 2.0 PF SP 2 PF Gas output 100% but leaks are not fully repaired	3.0 6.0 PF SP 3 H, 3 L	Same as MODERATE II A	1.5 3.0 PF SP 1.5 H, 1.5 L Gas output 100% but leaks are not fully repaired
SEVERE DAMAGE	6 psi Small pipe and components damaged. Valve itself is damaged. Damage results from impact by steel doors of vault	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	8.0 12.0 PF I - H SP - G Yes 4 PF I, 4 L, 4 IR IR Field repair not feasible, valve must be removed for shop repair	Same as SEVERE I A	6.0 12.0 PF I - H SP-G Rupture Disc or Valve Not Available 6 PF I, 6 L Valve replaced by rupture disc or manual valve and pressure gage. Gas output 100% but less reliable	18 26 PF I - H SP - G Yes 8 H, 8 L, 10 AM AS Field repair not feasible, valve must be removed for shop repair	Same as SEVERE II A	8 16 PF I - H SP - G - Rupture Disc or Valve Not Available 8 H, 8 L Valve replaced by rupture disc or manual valve and pressure gage. Gas output 100% but less reliable

G-18a COMPRESSOR - PRIME MOVER ASSEMBLY
DISTRIBUTION COMPRESSOR STATION

ASSUMES THAT PRIME MOVER (ELECTRIC MOTOR) AND COMPRESSOR (RECIPROCATING-TYPE) ARE LOCATED INSIDE A PREFAB TYPE STEEL MILL BUILDING. CONTROLS ARE ELECTRICAL & PNEUMATIC

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	2½ psi Small piping to auxiliaries and on exterior of compressor damaged by missiles	TOTAL TIME (hours)	40	40	32	50	50	
		EFFORT (man hours)	120	100	96	200	150	
		EQUIPMENT	PFI	PF	PF	PFI	[illegible]	
		SUPPLIES	SP·G	SP	SP	SP G	SP	
		SPARE PARTS	Yes	Incomplete	Incomplete	Yes	Incomplete	
		LABOR SKILLS (man hours)	40 PFI, 40 PF, 40M	30 PF, 20M	96 PF	100 H, 100 AM	100 H, 50 AM	
		SHOP FACILITIES						
		REMARKS		Some reduction in output due to imperfect cooling or lube oil piping	This is the minimum repair which will allow operation to resume		Some reduction in output due to imperfect cooling or lube oil piping	This is the minimum repair which will allow operation to resume.
MODERATE DAMAGE	7 psi Small piping virtually destroyed; large piping damaged but repairable	TOTAL TIME (hours)	100	90	75	200	150	120
		EFFORT (man hours)	400	260	300	600	450	360
		EQUIPMENT	PFI·H·W	PFI·H·W	PFI, H, W	PFI, H, W	PFI, H, W	PFI, H, W
		SUPPLIES	SP·LP·G	SP·LP·G	SP·LP·G	SP·LP·G	SP, LP, G	SP, LP, G
		SPARE PARTS	Yes	Incomplete	Incomplete	Yes	Incomplete	Incomplete
		LABOR SKILLS (man hours)	200 PFI, 100 PFW, 100M	180 PFI, 90 PFW, 90 M	150 PFI, 75 PFW, 75 M	300 H, 300 AM	225 H, 225 AM	180 H, 180 AM
		SHOP FACILITIES						
		REMARKS		Some reduction in output due to imperfect cooling or lube oil piping	This is the minimum repair which will allow operation to resume		Some reduction in output due to imperfect cooling or lube oil piping	This is the minimum repair which will allow operation to resume
SEVERE DAMAGE	25 psi Compressor and motor displaced on foundations. Major piping badly damaged; small piping almost completely destroyed	TOTAL TIME (hours)	300	250	200	350	300	250
		EFFORT (man hours)	1200	1000	800	1800	1500	1350
		EQUIPMENT	PFI, H, W, Jacks	PFI, H, W, Jacks	PFI, H, W	PFI, H, W, Jacks	PFI, H, W, Jacks	PFI, H, W, Jacks
		SUPPLIES	SP, LP, G	SP, LP, G	SP·LP·G	SP·LP·G	SP, LP, G	SP, LP, G
		SPARE PARTS	Yes	Incomplete	Incomplete	Yes	Incomplete	Incomplete
		LABOR SKILLS (man hours)	600 PFI, 300 PFW, 300 M, MAC	500 PFI, 250 PFW, 250 M, MAC	[illegible] PFI, 200 PFW, 200 M, MAC	600 H, 600 AM, 600 L, AS	500 H, 500 AM, 500 L, AS	450 H, 450 AM, 450 L, AS
		SHOP FACILITIES						
		REMARKS			Partial repair prevents full speed or pressure operation. Gas output limited to 75%			Partial repair prevents full speed or pressure operation. Gas output limited to 75%.

G-18 b MAJOR PIPING AND VALVING
DISTRIBUTION COMPRESSOR STATION

ASSUME THAT PIPING SYSTEM IS ABOVE GROUND, SOME OUTDOORS, SOME INSIDE STEEL COMPRESSOR BUILDING, AND IS SUPPORTED BY BUT NOT RIGIDLY ATTACHED TO PIPE SADDLES

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	~2-10 psi Minor [illegible] leakage from pipe displacement	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	8 16 PFI, W SP, G 8 PFI, 8 PFW	Same as LIGHT IA	6 12 PFI, W SP, G 6 PFI, 6 PFW This is the minimum repair which will allow operation to resume	16 32 PFI, W SP, G 16 H, 16 AM	12 24 PFI, W SP, G 12 H, 12 AM	10 20 PFI, W SP, G 10 H, 10 AM This is the minimum repair which will allow operation to resume
MODERATE DAMAGE	~10-15 psi Broken valves and fittings, distortion and displacement of pipe	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	20 60 PFI, W, H SP, LP, G Yes 20 PFI, 20 PFW, 20 L	16 48 PFI, W, H SP, LP, G Incomplete 16 PFI, 16 PFW, 16 L Partial repairs result in some loss of performance	12 36 PFI, W, H SP, LP, G Incomplete 12 PFI, 12 PFW, 12 L This is the minimum repair which will allow operation to resume	40 120 PFI, W, H SP, LP, G Yes 40 H, 40 L, 40 AM	32 96 PFI, W, H SP, LP, G Incomplete 32 H, 32 L, 32 AM Partial repairs result in some loss of performance	24 72 PFI, W, H SP, LP, G Incomplete 24 H, 24 L, 24 AM This is the minimum repair which will allow operation to resume
SEVERE DAMAGE	~20 psi Damaged to point where full reconstruction is required	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	50 200 PFI, W, H SP, LP, G Yes valve, fittings 50 PFI, 50 PFW, 100 L	Same as SEVERE IA	50 300 PFI, W, H SP, LP, G Incomplete 50 PFI, 150 PFW, 100 L Fabricate makeshift parts. Gas output reduced to 60%	80 320 PFI, W, H SP, LP, G Yes 140 H, 140 AM	Same as SEVERE IIA	80 400 PFI, W, H SP, LP, G Incomplete Fabricate make shift parts Gas output reduced to 60%

G-18c ELECTRICAL CONTROL SYSTEM
DISTRIBUTION COMPRESSOR STATION

ASSUMES THAT ELECTRIC CONTROLS (FOR CONTROLLING ELECTRIC MOTOR PRIME MOVERS) ARE LOCATED INSIDE THE STEEL COMPRESSOR BUILDING

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	1½ psi Field repairable damage to indicating instruments and low voltage control devices. No damage to main drive motor power wiring or controls.	TOTAL TIME (hours)	8	6	4	16	12	10
		EFFORT (man hours)	16	12	8	32	24	20
		EQUIPMENT	E	E	E	E	E	E
		SUPPLIES	E	E	E	E	E	E
		SPARE PARTS	Yes	No	No	Yes	No	No
		LABOR SKILLS (man hours)	16 E	12 E	8 E	32 H	24 H	20 H
		SHOP FACILITIES						
		REMARKS	Assumes full availability of replacement parts	Gas output 100% Electrical system less than fully functional.	This is the minimum repair which will allow operation to resume	Assumes full availability of replacement parts	Gas output 100% Electrical system less than fully functional.	This is the minimum repair which will give 100% gas output
MODERATE DAMAGE	2½ psi Control console displaced and knocked to floor. Connecting conduit and wire damaged. Major electrical elements such as reduced voltage starting essentially undamaged	TOTAL TIME (hours)	32	24	16	48	32	24
		EFFORT (man hours)	64	48	32	96	64	48
		EQUIPMENT	EX H	EX H.	EX H	EX H	EX H	EX H
		SUPPLIES	EX	EX	EX	EX	EX	EX
		SPARE PARTS	Yes			Yes		
		LABOR SKILLS (man hours)	64 E	48 E	32 E	54 H, 32 L	32 H, 32 L	32 H, 16 L
		SHOP FACILITIES						
		REMARKS	Not a true "back to normal" repair but a good job without factory replacement	Gas output 100% Electrical system less than fully functional	This is the minimum repair which will give 100% gas output.	Not a true "back to normal" repair but a good job without factory replacement.	Gas output 100% Electrical system less than fully functional.	This is the minimum repair which will give 100% gas output.
SEVERE DAMAGE	5 psi Control console damaged beyond repair by missiles and displacement.	TOTAL TIME (hours)	54	48	40	72	54	40
		EFFORT (man hours)	108	96	120	144	108	200
		EQUIPMENT	EX H	EX H	EX H	EX H	EX H	EX H
		SUPPLIES	EX	EX	EX	EX	EX	EX
		SPARE PARTS	Complete Console	Complete Console	Switches, Fuses, Starter	Complete Console	Complete Console	Switches, Fuses, Starter
		LABOR SKILLS (man hours)	108 E	96 E	80 E, 40 L	108 H, 36 L	72 H, 36 L	160 H, 40 L
		SHOP FACILITIES						
		REMARKS	Factory-made replacement; finished installation	Factory-made replacement; rough installation	Standard elements assembled in makeshift circuit to provide basic control functions. Gas output 100% but some loss of control	Factory-made replacement; finished installation	Factory-made replacement; rough installation	Standard elements assembled in makeshift circuit to provide basic control functions. Assumes that general supervision has the necessary elec knowledge. Gas output 100%

G-18d COOLING TOWER
DISTRIBUTION COMPRESSOR STATION

ASSUMES THAT COOLING TOWER IS EXPOSED AND FREE-STANDING. UNIT IS STEEL-FRAME COMMERCIAL PACKAGE-TYPE WITH WOODEN LATHS AND SIDING

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	1½ psi A considerable amount of lathwork is broken, but the tower is still functional.	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	10 20 C — Genuine Repl. 20 C Repair with factory-cut laths	12 24 C LM Not Available 24 C Repair with field-cut laths.	4 8 C — Not Available 8 C Clear debris and loose items. No replacement of laths Output reduced to 70%	20 40 C — Genuine replacement 20 H, 20 L Repair with factory cut laths.	24 48 C LM Not available 24 H, 24 L Repair with field cut laths.	6 12 C — Not available 6 H, 6 L Clear debris and loose items. No replacement of laths. Output reduced to 70%.
MODERATE DAMAGE	2 psi Lathwork gone. Damaged frame and fan remain	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	36 180 C·PF·W E SP·Steel·E Lath and fan parts — Repair with factory-cut laths	50 250 C PF·W·E LM SP Steel·E Fan Parts 170 C, 20 L, 20 PF, 24 M, 16 E General Shop Repair with field-cut laths.	40 180 C·PF LM·SP·Steel Not Available 120 C, 20 L, 40 PF Without a fan, the output is reduced to 50%.	48 240 C·PF W·E SP·Steel E Lath and Fan Parts 120 H, 120 L Repair with factory cut laths.	100 500 C·PF·W·E LM·SP·Steel·E Fan parts 250 H, 250 L General Shop Repair with field-cut laths	60 240 C·PF LM-SP-Steel Not available 120 H, 120 L Without a fan, the output is reduced to 50%
SEVERE DAMAGE	3 psi Tower completely destroyed, materials scattered Foundation basin remains useable.	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS (man hours) SHOP FACILITIES REMARKS	50 300 C·PF·W·E H { factory package unit 150 C, 50 PF, 50 M, 50 E Erect factory package unit	120 600 C·PF·W·E·H LM·SP·Steel·E complete fan assembly 100 M, 350 C, 50 L, 50 PFW, General Shop Erect field-fabricated unit.	40 320 C·H·PF·W LM·SP LP — 180 C, 80 L, 60 PFW Improvised design without fan. Output reduced to 30%	75 450 C·PF·W·E·H { Factory Package Unit 225 H, 225 L Erect factory package unit.	240 1200 C·PF·W·E·H LM·SP-Steel E complete fan assy. 600 H, 600 L General Shop Erect field fabricated unit.	80 480 C·H·PF·W LM-SP LF — 240 H, 240 L Improvised design without fan Output reduced to 30%

G-18e PREFAB STEEL BUILDING
DISTRIBUTION COMPRESSOR STATION

ASSUMES THAT THE COMPRESSOR BUILDING IS OF THE MODULAR, PREFAB, COMMERCIAL MILL BUILDING TYPE (SHEET STEEL PANELS WITH SEPARATE STRUCTURAL STEEL FRAMEWORK AND CROWN SUPPORT) AVERAGE NO. OF WINDOWS & DOORS.

	DAMAGE DESCRIPTION	REQUIRED RESOURCES	I A	I B	I C	II A	II B	II C
LIGHT DAMAGE	1½ psi 50% of roofing and side panels are damaged or missing	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS	The prefab nature of the building makes repair to condition "A" impossible without full availability of factory-supplied parts	24 72 Crane Fasteners, sheet metal, etc. Clips, etc. Steelworkers Repair roofing and siding. Replace paneling with sheet metal where necessary	24 72 Crane Fasteners, paneling, etc. Carpenters Replace damaged roofing and siding with any type exterior-duty paneling (plywood, corrugated steel, etc.)	Same as LIGHT IA	48 144 Crane Fasteners, sheet metal, etc. Clips, etc. Steelworkers Repair roofing and siding. Replace paneling with sheet metal where necessary	48 144 Crane Fasteners, paneling, etc. Carpenters Replace damaged roofing and siding with any type of exterior-duty paneling (plywood, corrugated steel, etc.)
MODERATE DAMAGE	2½ psi All roofing and siding stripped off. Steel frame distorted	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS	Same as LIGHT IA	80 320 Crane, cutting & welding equip. Fasteners, sheet metal Steelworkers Straighten and repair damaged frame. Replace damaged or missing paneling	Same as MODERATE IB	Same as LIGHT IA	160 640 Crane, cutting & welding equip. Fasteners, sheet metal Steelworkers Straighten and repair damaged frame. Replace damaged or missing paneling	Same as MODERATE IIB
SEVERE DAMAGE	6 psi Building virtually destroyed. Only the foundation is intact. No building components are salvageable for reuse	TOTAL TIME (hours) EFFORT (man hours) EQUIPMENT SUPPLIES SPARE PARTS LABOR SKILLS SHOP FACILITIES REMARKS	Same as LIGHT IA	100 500 Crane Steelworkers Erect a new building of similar design on the existing foundation. Above estimate does not include the time or other resources required for shop prefabrication	Build a suitable sheltering structure out of available materials. No time estimate is possible	Same as LIGHT IA	200 1000 Crane Steelworkers Erect a new building of similar design on the existing foundation. Above estimate does not include the time or other resources required for shop prefabrication	Same as SEVERE IIB

THE REPAIR ANALYSIS OF ELECTRIC UTILITY SYSTEMS

For convenience, the electric utility system was divided into three major systems: generation, transmission, and distribution. The elements comprising these systems are shown on the overview diagram (Fig. 2) and are keyed by number on Fig. 4 to the repair analysis summary sheets (Tables E-1 through E-14).

The following comments describe the criteria and limitations that were used in deriving the repair analysis charts:

- Essentially, where complete destruction is indicated, the man-hours required for a new facility have been used, and a 10-percent factor added for demolition and removal of debris.
- All man-day figures are based on an 8-hour day.
- Cannibalization is not indicated in the table but is possible. It may well be the best interim solution, since many manufacturing plants will be out of commission for an indefinite period. The man-hour figures for dismantling equipment and transportation are not represented in the table, but will be close to the installation cost if foundations and housings are excluded.
- Operating and maintenance staff have not been considered in this study, but typically requirements are 0.175 employees per MW for the 330-MW units under consideration.
- Those items assumed to be generally furnished as the complement of a typical utility repair truck or readily available from local sources have not been included in the Repair Analysis Sheets as required equipment or supplies.

E-1 COAL CONVEYOR & ROTARY CAR DUMP
FUEL HANDLING SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPEDIENT	DEGRADED	COMMENTS
	I. [illegible]				II. [illegible]		EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
	1. [illegible]		2. [illegible]	3. [illegible]	4. [illegible]	5. [illegible]								
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]								
3-4 psi Conveyor Housing partially damaged, siding torn off, belt jammed. Damage to housing begins at 1.5 psi	150	15	60	20	120	40	crane welding equipment	metal siding belt patches	rollers	Steelworker (5) millwright (2) electrician (2) equip op (1) rigger (1)	steelworker (1) millwright (1) electrician (1) equip op (1) any (7)	Use wooden siding	Repair but only run conveyor 50% speed	
5 psi Conveyor housing fails and belt rips	375	40	150	100	300	200	crane welding equipment	metal siding belt patches struts	rollers	Steelworker (3) millwright (2) electricians (2) equip op (1) rigger (1)	steelworker (1) millwright (1) electrician (1) equip op (1) any (7)	Same as above	Same as above	
7-? psi Complete failure of conveyor housing and structure	750	80	600	500	1200	1000	crane welding equipment	metal siding struts	new conveyor belt with all necessary equipment	Steelworker (4) millwright (?) electrician (2) equip op (1) rigger (1)	steelworker (1) millwright (1) electrician (1) equip op (1) any (8)	Same as above	Same as above	
16-20 psi Rotary car dumper fails, structure deformed.	1250	90	500	375	1000	875	crane welding equipment		new car dumper	steelworker (6) millwright (5) electrician (2) equip op (1) rigger (1)	steelworker (2) millwright (2) electrician (1) equip op (1) any (15)			

E-2 COAL PULVERIZERS
FUEL HANDLING SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days) I. [illegible] A. [illegible] Man-Days	Time	B. [illegible] Man-Days	C. [illegible] Man-Days	II. [illegible] B. [illegible] Man-Days	C. [illegible] Man-Days	RESOURCES NECESSARY FOR REPAIR: EQUIPMENT	SUPPLIES	SPARE PARTS	LABOR SKILLS: REQUIRED	ALTERNATE	PER EXPEDIENT	DEGRADED	COMMENTS
6 psi and missle Burners at boiler knocked loose	10 each	5 each	100 per boiler	160 per boiler	750 per boiler	450 per boiler	hoist welder flame cutter compressor	steel pipe insulation lagging	burner	boiler maker (1) helper (1)	boiler maker (1) any (1)	Delete 2 or 3 burners per boiler = 90% eff	Delete 50% of burners per boiler 55% capacity	repair facilities required [illegible] 4 burners per pulverizer
1-10 psi Fracture of connections to a) pulverizers b) hot air duct to pulverizer c) feeder to pulverizer (coal input)	20 each 5 each 15 each	10 each 3 each 5 each	— — 15 each	80 per boiler 21 per boiler 65 per boiler	— — 35 each	200 per boiler 50 per boiler 150 per boiler	hoist, welder, flame cutter, compressor same as above same as above	steel plate, steel pipe, bolts steel plate, lagging, expansion joints, insulation steel plate, bolts	— — —	boiler maker (1), millwright (1), welder (1) boiler maker (2), welder (1) boiler maker (1), welder (1)	boiler maker (1), any (4) boiler maker (1), any (1) boiler maker (1), any (4)	none none substitute rubber and wood, etc. for steel feeder	Delete 50% of pulverizers Delete 50% of pulverizers and ducts to same Delete feeders for 50% of pulverizers	8 pulverizers per boiler

E-3a AIR HEATER, SOOT BLOWER & DUST COLLECTOR
BOILER SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		FOR EXPEDIENT	DEGRADED	COMMENTS
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
6-7 psi Moderate damage to a) air heater b) soot blowers c) dust collector connections ruptured walls distorted	350 each 2 each 500 each	40 each 1 each 55 each	350 each 30 per boiler 150 per boiler	450 per boiler 50 per boiler 150 per boiler	700 each 120 per boiler 400 per boiler	900 per boiler 120 per boiler 400 per boiler	Hoist welder flame cutter compressor	steel plate insulation angle iron lagging		boiler maker (4) boiler helper (4) welder (1) boilermaker (2) boilermaker (4) boiler helper (4) welder (2)	boilermaker (3) any (4) boilermaker (1) any (1) boilermaker (1) any (4)	none for air heater soot blowers and dust collectors can be shutdown temporarily No loss in boiler eff. by omitting soot blowers and dust col., except eventual slagging of boiler	lose one air heater - 50% capacity bypass soot blowers and dust collectors	2 air heaters/boiler 50 soot blowers/boiler 2 dust coll/boiler
8-10 psi walls collapse a) air heater b) soot blower c) dust collector	800 each 8 each 750 each	85 each 4 each 80 each	600 per boiler 100 per boiler 240 per boiler	900 per boiler 100 per boiler 200 per boiler	2000 each 250 per boiler 500 per boiler	2400 each 250 per boiler 500 per boiler	hoist welder flame cutter compressor	steel plate insulation bolts angle iron lagging		boiler maker (4) boiler helper (4) welder (2) boilermaker (2) boilermaker (4) boiler helper (4) welder (2)	boilermaker (3) any (6) boilermaker (1) any (1) boilermaker (3) any (4)	none for air heater, soot blowers and dust collectors can be shut down temporarily	Same as above	

E-3b HOT AIR DUCT & FLUES
BOILER SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days) I. SKILLED MANPOWER: 1. [illegible] MAN-DAYS	1. [illegible] TIME	2. SUPER. MAN-DAYS	3. [illegible] MAN-DAYS	II. [illegible] MANPOWER: 4. [illegible] MAN-DAYS	5. [illegible] MAN-DAYS	RESOURCES NECESSARY FOR REPAIR: EQUIPMENT	SUPPLIES	SPARE PARTS	LABOR SKILLS: REQUIRED	ALTERNATE	PER EXPEDIENT	DEGRADED	COMMENTS
6-8 psi Connections broken duct buckles (hot air duct and flues)	4000 per boiler	280 per boiler	2800 per boiler	1800 per boiler	7000 per boiler	4500 per boiler	hoist flame cutter welder compressor	sheet plate insulation bolts angle iron lagging		boilermaker (8) boiler helper (6) welder (3)	boilermaker (5) any (17)	air heater duct must be repaired Soot blowers and dust collectors can be shutdown	delete one air heater - 50% capacity bypass soot blowers and dust collectors	
10-12 psi Complete destruction to hot air duct and flues	16,500 per boiler	5500 per boiler	11,500 per boiler	7,000 per boiler	29,000 per boiler	11,000 per boiler	crane hoist flame cutter compressor welder	sheet plate insulation bolts angle iron lagging conduit and wire	new fan fan starter	millwright (4) boilermaker (8) boiler helper (8) welder (4) electrician (3) eqpt op (1) rigger (1)	millwright (2) boilermaker (5) electrician (1) eqpt op (1) any (25)	air heaters, fans and duct to same must be repaired or replaced Soot blowers and dust collectors can be shutdown	Delete one fan - 50% capacity	repair facilities required - repair shop for fan (bent shaft, etc)

E-4 BOILER

BOILER SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days) I. [illegible] A. [illegible]	I. [illegible]	I. B. [illegible]	I. C. [illegible]	II. [illegible] A. [illegible]	II. B. [illegible]	RESOURCES NECESSARY FOR REPAIR: EQUIPMENT	SUPPLIES	SPARE PARTS	LABOR SKILLS: REQUIRED	ALTERNATE	PER EXPEDIENT	DEGRADED	COMMENTS
4-5 psi and missle Holing of walls (corner bracket and missle) Distortion of walls	800 per boiler 1500 per boiler	20 per boiler 35 per boiler	500 per boiler 1000 per boiler	800 per boiler 1500 per boiler	2000 per boiler 5000 per boiler	2000 per boiler 8000 per boiler	crane hoist welder flame cutter hydraulic jack compressor	insulation lagging new wall sections	boiler tubes	boilermaker (20) boiler helper (20) welder (1) eqpt op (1) rigger (1)	boilermaker (19) eqpt op (1) any (35)	none some distortion may be left if tubes not cracked	none	Only certified welders should be used for boilers
5-6 psi and missle Boiler tubes broken	3000 per boiler	70 per boiler	3000 per boiler	3700 per boiler	7000 per boiler	7000 per boiler	crane hoist flame cutter hydraulic jack compressor welder	new wall sections [illegible] insulation lagging	boiler tubes	boilermaker (20) boiler helper (10) welder (5) eqpt op (1) rigger (1)	boilermaker (8) eqpt op (1) any (35)	none	none	
10-12 psi Piping cracked and broken at connections due to differential movement and failure of roof.	3500 per boiler	40 per boiler	3500 per boiler	2500 per boiler	9000 per boiler	4000 per boiler	crane hoist welder flame cutter compressor	steel piping insulation bolts lagging	—	boilermaker (10) boiler helper (20) steam fitter (10) welder (3) eqpt op (1) rigger (1)	boilermaker ([illegible]) steam fitter ([illegible]) eqpt op (1) any (38)	none	none	These are assumed external to the boiler only
14-20 psi Complete destruction	27,000 per boiler	450 per boiler	21,000 per boiler	16,000 per boiler	57,000 per boiler	45,000 per boiler	crane hoist welder flame cutter compressor	insulation lagging steel piping	wall (tube) sections drum economizer reheater superheater steel columns beams pipe supports	boilermaker (15) boiler helper ([illegible]) steamfitter (10) welder (8) carpenter (5) steel worker (6) eqpt op (2) rigger (2)	boiler maker ([illegible]) steamfitter (1) carpenter (1) steel worker (2) eqpt op (2) any (45)	delete economizer (~3% loss of eff)	delete superheater ([illegible]) delete economizer ([illegible]) delete reheater ([illegible])	[illegible]

E-5 FORCED - DRAFT FAN
BOILER SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPEDIENT	DEGRADED	COMMENTS
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
[illegible]	[illegible] each	[illegible]	[illegible] each	[illegible] per boiler	12½ each	15o per boiler	hoist welder flame cutter compressor	steel plate insulation lagging	---	boilermaker (1) boilermaker helper (1) millwright (1) welder (1)	[illegible] (1) millwright (1) any (1)	none	bypass one fan 50% loss in boiler output	two fans per boiler
[illegible]	[illegible] each	[illegible] each	[illegible] each	[illegible] per boiler	[illegible] each	[illegible] per boiler	crane hoist welder flame cutter compressor	steel plate insulation lagging [illegible] conduit and wire	fan fan starter	boilermaker (2) boiler helper (1) millwright (1) carpenter (1) electrician (1) welder (1) eqpt op (1) rigger (1)	boilermaker (1) millwright (1) carpenter (1) electrician (1) eqpt op (1) any (2)	none	bypass one fan	repair facilities required [illegible] for fan

E-6a COOLING WATER INTAKE
WATER SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPEDIENT	DEGRADED	COMMENTS
	I [illegible]				II [illegible]									
	1. [illegible] [illegible]	[illegible]	2. [illegible] [illegible]	3. [illegible] [illegible]	4. [illegible] [illegible]	5. [illegible] [illegible]	EQUIPMENT	SUPPLIES	SPARE PARTS	PREFERRED	ALTERNATE			
11 psi Cooling water intake and screen house collapsed and jammed with debris Cooling water pump slightly damaged	500 per condenser	4? per condenser	400 per condenser	300 per condenser	1000 per condenser	750 per condenser	crane welder compressor	concrete rebar	travelling screen	cement worker(?) carpenter(3) iron worker(2) welder(2) millwright(2) electrician(2) eqpt op (1) rigger (1)	construction(?) ironworker(1) millwright(1) electrician(1) eqpt op (1) any (10)	clear out all debris but screen may be stationary for short period, or must be manually cleaned	one pump may be shut down = 20% loss in output	repair facilities required - repair shop for screen 2 cooling water pumps/condenser
16.8 psi Moderate to severe damage of intake and screen Cooling water pump misaligned	2000 per condenser	86 per condenser	1100 per condenser	1200 per condenser	1800 per condenser	1000 per condenser	crane welder compressor	concrete rebar conduit and wire	travelling screen	cement worker(3) carpenter(4) iron worker (4) welder (1) millwright (4) pipefitter (4) electrician (2) eqpt op (1) rigger (1)	cement worker(?) iron worker (2) millwright (?) pipefitter (1) electrician(1) eqpt op (1) any (20)	minimum of fixed screen must be installed and cleaned manually	same as above	repair facilities required - repair shop for screen and pumps

E-6b CONDENSER & HOT WELL PUMP
WATER SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPERIMENT	DEGRADED	COMMENTS
	I. [illegible]				II. [illegible]									
	A. [illegible]		B. [illegible]	C. [illegible]	A. [illegible]	B. [illegible]	EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]								
15-18 psi Misalignment between hotwell, pump and motor, casing damaged	50 each	5 each	65 per condenser	165 per condenser	150 per condenser	150 per condenser	crane compressor	bolts	--	millwright (10) eqpt op (1) rigger (1)	millwright (3) eqpt op (1) any (8)	Bypass one hotwell pump-noless of eff	Bypass . . hotwell pump	2 hotwell pumps per condenser
40 psi Building collapse damage to condenser, casing ruptured, tubes broken	350 per condenser	40 per condenser	---	200 per condenser	--	500 per condenser	crane hoist jack welder compressor		tubes casing sections	steamfitter (2) boilermaker (8) welder (1) eqpt op (1) rigger (1)	boilermaker (2) steamfitter (1) eqpt op (1) any (10)	none	one half of condenser may be shut down = 50% loss output	

E-7 FEEDWATER PUMP & DEAERATOR
BOILER SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days): I. [illegible]: A. [illegible]: Man-Days	I. A.: Time	I. B. [illegible]: Man-Days	I. C. [illegible]: Man-Days	II. [illegible]: B. [illegible]: Man-Days	II. C. [illegible]: Man-Days	RESOURCES NECESSARY FOR REPAIR: EQUIPMENT	SUPPLIES	SPARE PARTS	LABOR SKILLS: REQUIRED	SUBSTITUTE	ALT EXPEDIENT	DEGRADED	COMMENTS
5-7 psi Heater defects, piping and connections broken	200 per boiler		160 per boiler	70 per boiler	400 per boiler	180 per boiler	crane hoist welder flame cutter compressor	piping insulation lagging tubing	-	steamfitter (4) pipefitter (4) welder (1) eqpt op (1) rigger (1)	steamfitter (1) pipefitter (1) eqpt op (1) any (10)	bypass two reheaters ≈ 10% loss in eff.	bypass all reheaters ≈ 15% loss in eff	[illegible] feedwater pumps per boiler 6 reheaters per boiler [illegible] deaerator per boiler
8-10 psi Piping failure/light damage to pump. Feedwater heater overturns, breaks. Deaerator overturns and breaks	2000 per boiler		1500 per boiler	900 per boiler	3800 per boiler	2200 per boiler	crane hoist welder flame cutter compressor	insulation lagging tubing	feedwater heater pipes pump parts	steamfitter (6) pipefitter (6) electrician (2) welder (2) rigger (1) eqpt op (1)	steamfitter (2) pipefitter (2) electrician (1) eqpt op (1) any (12)	bypass two reheaters ≈ 10% loss in eff	bypass all reheaters and deaerator ≈ 15% loss in eff bypass one feedwater pump	repair facilities required repair shop for feedwater heater
15-20 psi Misalignment between pump and motor	50 each	5 each	60 per boiler	60 per boiler	150 per boiler	150 per boiler	crane compressor	bolts	- -	millwright (4) eqpt op (1) rigger (1)	millwright (2) eqpt op (1) any (4)	bypass one feedwater pump ≈ no loss in eff.	bypass one feedwater pump	

E-8 TURBO-GENERATOR, LUBRICATION & HYDROGEN COOLING
TURBO-GENERATOR SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPEDIENT	DEGRADED	COMMENTS
	I. [illegible]				II. [illegible]		EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
	A. [illegible]		B. [illegible]	C. [illegible]	B. [illegible]	C. [illegible]								
	MAN-DAYS	TIME	MAN-DAYS	MAN-DAYS	MAN-DAYS	MAN-DAYS								
7 psi Hydrogen piping broken hydrogen tank truck overturned	130 per turbine	20 per turbine	150 per turbine	15 per turbine	120 per turbine	30 per turbine	welding or brazing equipment compressor	small pipe valves	hydrogen storage bottles tank truck	pipefitter (6) welder (1)	pipefitter (2) any (6)	none	eliminate hydrogen cooling: 40% loss in KVA output.	Possible fire when hydrogen piping is broken
12-15 psi [illegible] Turbo gen. [illegible] damage broken piping Case system rupture [illegible] Bearing [illegible] to [illegible] parts [illegible]	250 per turb 250 per turb	25 per turb 20 per turb	25 per turb 250 per turb	25 per turb 250 per turb	60 per turb 600 per turb	60 per turb 600 per turb	crane welder flame cutter compressor	piping valves	oil filter gen case sections bearings	pipefitter (6) millwright (2) eqpt op (1) rigger (1) electrician (4) pipefitter (1) millwright (10) eqpt op (1) rigger (1)	pipefitter (1) millwright (1) eqpt op (1) electrician (1) any (10) pipefitter (1) millwright (8) eqpt op (1) any (12)	if controls undamaged leave as is - cover with tarpaulin if outdoors none	if controls undamaged leave as is cover with tarpaulin if outdoors	repair facilities required local machine shop
15-20 psi Turbo gen. shaft in [illegible] good	50 per turb	12 per turb	50 per turb	50 per turb	125 per turb	125 per turb	crane compressor	—	—	millwright (5) eqpt op (1) rigger (1)	millwright (2) eqpt op (1) any (4)	none	none	

E-9 EXCITER & STATION AUXILLIARY BUS
EXCITER SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days) I. QUALIFIED MANPOWER A. PERFORMING REPAIRS MAN-DAYS	I. A. TIME	I. B. SUPER. MAN-DAYS	I. C. GENERAL MAN-DAYS	II. MANPOWER B. SUPER. MAN-DAYS	II. C. GENERAL MAN-DAYS	RESOURCES NECESSARY FOR REPAIR: EQUIPMENT	SUPPLIES	SPARE PARTS	LABOR SKILLS: REQUIRED	ALTERNATE	PER EXPEDIENT	DEGRADED	COMMENTS
7 psi and missile Exciter and aux. station bus dislocated and insulators broken Also bus between generator and transformer	800 per generator	70 per gen	400 per gen	400 per gen	1000 per gen	1000 per gen	hoist crane	insulators bus enclosure bus	—	electrician (8) eqpt-op (1) rigger (1)	electrician (4) eqpt-op (1) any (10)	provide insulated cables in lieu of bus except gen. bus must be repaired	provide insulated cables in lieu of exciter and station bus except gen bus must be repaired	
10 psi Exciter and prime mover shaft misalignment	30 each	6 each	0	—	0	—	crane welder compressor	bolts shims	—	electrician (4) eqpt-op (1) rigger (1) welder (1)	electrician (1) eqpt-op (1) any (5)	If standby exciter is intact use in lieu of regular unit	none	
12-14 psi Casing and shaft damage due to building wall collapse	50 each	10 each	30 each	—	8 each	—	crane, lter flame-cutter compressor	—	new exciter unit	electrician (3) millwright (1) welder (1) eqpt-op (1) rigger (1)	electrician (1) millwright (1) eqpt op (1) any (5)	Salvage D.C. gen or motor from steel mill or industrial plant and reconnect generator	none	repair facilities required - local service shop
—														

E-10 METERING PROTECTION & CONTROL
CONTROL SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPEDIENT	DEGRADED	COMMENTS
	I. [illegible]				II. [illegible]									
	A. [illegible]		B. [illegible]	C. [illegible]	B. [illegible]	C. [illegible]	EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
	[illegible]	Time	[illegible]	[illegible]	[illegible]	[illegible]								
2 ps and missile Meters and relays broken and inoperable Bending of shafts and broken arms 6/cubicle	1 each	1 each	2 each	1 each plus standby operating personnel	11 each	2 each plus standby operating personnel	hand tools	meters relays lamps fuses		wireman (1)	white collar (1) or professional (1)	replace meters or relays with alternat. devices e.g. synchronizing lights in lieu of synchro-meter	hand operate in lieu of automatic control	repair facilities required metal shop
4 ps and missile Electrical connections broken and cubicles deformed (Does not include meters or relays)	10 per cubicle	5 per cubicle	6 per cubicle	4 per cubicle plus standby operating personnel	15 per cubicle	10 per cubicle plus standby operating personnel	hoist hand tools	angle iron sheet metal wire connectors terminal blocks		wireman (2)	wireman (1) any (2)	as above leaves cubicles deformed, repair of broken electrical connections	same as above	
8 ps and missile All systems and wiring severely damaged Controls and metering require replacement	40 per cubicle	10 per cubicle	20 per cubicle	6 per cubicle plus standby operating personnel	60 per cubicle	20 per cubicle plus standby operating personnel	hoist hand tools flame cutter	wire connectors control cables lamp fuses	new control cubicles and consoles	wireman (4)	wireman (1) any (6)	temporary wood panels with indicating lights and control switches protective devices and certain automatic controls not used. splice cables	same as above	

E-11 CIRCUIT BREAKERS & BUS STRUCTURE
TRANSMISSION SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days) I. [illegible]				II. [illegible]		RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		FOR EXPEDIENT	DEGRADED	COMMENTS
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
4.5 psi & missile Permanent deformation of Bus Structure 10% insulator breakage circuit breaker insulators broken unit = 1 disconnect	20 per unit 3 per insulator 15 per cir breaker	7 per unit 1 per insulator 5 per cir breaker	10 per unit 3 per insulator 15 per cir breaker	30 per transformer 10 per transformer 2 per transformer	30 per unit 4 per insulator 40 per cir breaker	90 per transformer 30 per transformer 6 per transformer	crane compressor	copper bus steel tubing insulators bushings oil		electricians (8) crane-op (1) rigger (1) electricians (5) crane-op (1) rigger (1) electricians (8) crane-op (1) rigger (4)	electricians (1) any (1) electricians (1) any (1) electrician (1) any (8)	Replace all insulators but leave bus structure deformed if electrical clearance maintained	Isolate all but necessary circuits to few transformers Eliminate circuit breakers and isolating disconnects where used for interconnection Bypass all circuit breakers and disconnects if all damaged	
6 psi Bus Structure partially collapsed Small circuit breakers overturned	150 per transformer 30 each	14 per transformer 5 each	25 per transformer	15 per transformer	40 per transformer	90 per transformer	crane welder flame-cutter compressor	copper bus steel tubing insulators disconnects bushings oil		electricians (4) crane-op (1) rigger (1) electrician (8) crane-op (1) rigger (1)	electrician (4) crane-op (1) any (1) electrician (1) crane-op (1) any (8)	Use wood structures instead of steel Bypass circuit breaker	Same as above	
7 psi Bus Structure full collapsed (does not include disconnects, circuit breakers or transformers)	300 per transformer	25 per transformer	15 per transformer	20 per transformer	40 per transformer	30 per transformer	crane welder flame cutter compressor	copper bus steel tubing insulators disconnects		electrician (4) crane-op (1) rigger (1)	electrician (4) crane-op (1) any (11)	Same as above	Same as above also install power cables directly or ground in lieu of overhead transmission	
15-20 psi Large circuit breakers overturned	50 each	15 each	10 each	10 each	30 each	30 each	crane	bushings oil		electrician (4) crane-op (1) rigger (1)	electrician (1) crane-op (1) any (4)	bypass circuit breaker	bypass circuit breaker	

E-12a 200 MW TRANSFORMERS
TRANSMISSION SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPEDIENT	DEGRADED	COMMENTS
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
5 psi Thus psi thermal breakdown of transformer oil due to thermal pulse and short and internally Oil and windings must be treated	40 each (oil replacement) 80 each (oil damage)	16 each 18 each	O —	— —	O —	— —	Crane Oil Filter Press	oil Nitrogen	new coil	electrician(4) electrician (5) eqpt op (1) rigger (1)	electrician (1) any (3) electrician (2) eqpt op (1) any (4)	10% oil breakdown acceptable on short term basis with transformer not more than 50% loaded	none	repair for 1 bus-type transformer shop for coil
6-9 psi and missile Power connections to transformers broken Porcelain bushings broken Fin deformation Insulators gone at 6 psi	170 each	15 each	175 each	3 each	450 each	90 each	Crane Oil Filter Press	Oil Nitrogen connectors copper bus		electrician (6) eqpt op (1) rigger (1)	electrician (4) eqpt op (1) any (13)	none	Bypass transformer and operate transmission line at reduced voltage or Remove fins and plug hole in side of tank - operate at 50% capacity	
10-12 psi Transformers overturned Fins deformed and ruptured *	300 each	20 each	360 each	40 each	150 each	120 each	Crane Oil Filter Press Jacks Rollers Bulldozers (2)	oil nitrogen connectors copper bus	coil (?) fins	electrician (18) eqpt op (1) rigger (4) crane op (1)	electrician (5) eqpt op (1) crane op (1) any (30)	none	same as above	Rep. & facilities required transformer shop for coil * Westinghouse type transformers would probably not require coil replacement

E-12b 15-45 MVA SUBSTATION TRANSFORMER
TRANSMISSION SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPERIMENT	DEGRADED	COMMENTS
	I. [illegible]				II. [illegible]									
	1. [illegible]		2. [illegible]	3. [illegible]	1. [illegible]	2. [illegible]	EQUIPMENT	SUPPLIES	SPARE PARTS	[illegible]	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]								
[illegible] Possible thermal breakdown of transformer oil due to thermal pulse	5 (oil replacement)	2	0	0	0	–	Crane Oil filter press	Oil Nitrogen		Electricians (3)	Electrician (1) Any (2)	0% oil breakdown acceptable on short term basis with transformer not more than 50% loaded	None	
Oil and windings must be checked	10 (oil damage)	2	–	–	–	–				Electricians (4) Eqpt op (1) Rigger (1)	Electrician (1) Eqpt op (1) Any (5)			
[illegible] Power connections to any transformer broken Porcelain bushings broken Fin deformation Insulators destroyed.	15	4	15	15	185	45	Crane Oil filter press	Oil Nitrogen Connectors Copper bus	New coil	Electricians (7) Eqpt op (1) Rigger (1)	Electrician (2) Eqpt op (1) Any (8)	None	Bypass transformer and operate from line at reduced voltage OR Remove fins and plug holes in tank of transformer, operate at 50% capacity	Repair facilities required Transformer shop for coil
[illegible] Transformer overturned Fins ruptured	125	12	125	20	300	60	Crane Oil filter press Jacks Rollers Bulldozer	Oil Nitrogen Connectors Copper bus	New coil Fins	Electricians (8) Eqpt op (1) Rigger (5) Crane op (1)	Electrician (2) Eqpt op (1) Crane op (1) Any (10)	None	Same as above	
—														

E-13 TRANSMISSION LINES, 110KV, 64KV AND 34KV TRANSMISSION SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPEDIENT	DEGRADED	COMMENTS
	I. [illegible]				II. [illegible]		EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	ALTERNATE			
	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]								
	[illegible]	TIME	[illegible]	[illegible]	[illegible]	[illegible]								
2-Tons + Missiles 34-64KV poles (wooden) Poles leaning + crossarms broken, lines down 110KV steel towers towers partially buckled	80/mile 320/mile	2 7	40/mile 185/mile	40/mile 185/mile	100/mile 425/mile	100/mile 425/mile	Auger Compressor Crane Trailer Tensioner Winches Pick up (2) Flat bed Splicer	Insulators Bolts Cable Angle Iron Concrete Rebar	Poles Guys Crossarms	Lineman (20) Groundman (15) Eqpt op (5) Rigger (5)	Lineman (4) Groundman (3) Eqpt op (1) Any (45)	Strap broken poles to stubs Use wooden pole substitutes	None None	
4-Tons 34 + 64 KV poles (wooden) Poles broken off above ground 110 KV steel towers fail	160/mile 440/mile	4 15	110/mile 130/mile	100/mile 100/mile	250/mile 850/mile	250/mile 850/mile	Same as above	Same as above	Same as above			Same as above Same as above	None None	
—														
—														

E-14 DISTRIBUTION LINES
DISTRIBUTION SYSTEM

DESCRIPTION OF DAMAGE	REPAIR EFFORT (Man-Days)						RESOURCES NECESSARY FOR REPAIR			LABOR SKILLS		PER EXPERIMENT	[illegible]	COMMENTS
	I. [illegible]				II. [illegible]		EQUIPMENT	SUPPLIES	SPARE PARTS	REQUIRED	AVAILABLE			
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]								
2 psi and missile Poles leaning crossarms broken insulators broken (10%)	35 /mile	4	20/mile	20 /mile	60/mile	60/mile	Boom truck winches tagger compressor	crossarms bolts insulators guys	crossarms	lineman (4) groundman (3) equipt op (1)	lineman (1) groundman (1) equipt op (1) any (6)	Strap broken poles to stubs	Strap broken poles to stubs	
4-5 psi Poles broken 6'-8' above ground Transformers on poles broken (5+ KVA)	14 /mile 2 /ea.	9 0.7 each	40/mile —	20/mile —	60/mile —	60/mile —	Boom truck winches tamper compressor auger butt puller pickup (1) flat-bed splicer	guys insulators bolts cable fuses disconnect	poles crossarms transformers arrestors	lineman (4) groundman (3) equipt op (1)	lineman (1) groundman (1) equipt op (1) any (6)	same as above none	same as above none	 repair facilities required transformer shop
8 psi Consumer service drop severed when house fails	0.5 each	0.25 each	—	—	—	—	Pick-up	cable		lineman (2)	lineman (1) any (1)	none	none	
—														

Appendix B

SUPPLEMENTARY REPAIR INFORMATION

TABLE B-1

Repair Estimate - Underground gas pipe leak (assumes that valves are present to shutoff pressure during repair)

	SKILL CLASSIFICATION	REPAIR EFFORT (man-hours/break)	TOTAL TIME REQUIRED (hours/break)
6-in. Steel (50-psi)	Foreman Laborer P.F. Welder Equip. Operator	5.1 14.1 2.6 1.0	6.4
2-in. Steel (5 psi)	Foreman Laborer Plumber Equip. Operator	3.8 10.3 1.3 1.0	5.2
4-in. Cast Iron (5 psi)	Foreman Laborer Plumber Equip. Operator	3.5 10.0 1.0 1.0	4.8
8-in. Cast Iron (7-in. W.C.)	Foreman Laborer Plumber Equip. Operator	3.5 10.0 1.0 1.0	4.8

Repair Estimate - Installation of gas line shutoff plugs (for use where valves are not present to shutoff pressure during repair)

	SKILL CLASSIFICATION	REPAIR EFFORT (man-hours/break)	TOTAL TIME REQUIRED (hours/break)
6-in. Steel (50 psi)	Foreman Laborer P.F. Welder Plumber Equip. Operator	6.9 28.6 7.6 5.0 2.0	6.4
2-in. Steel (5 psi)	Foreman Laborer P.F. Welder Plumber Equip. Operator	5.6 19.8 3.0 1.3 2.0	5.2
4-in. Cast Iron (5 psi)	Foreman Laborer Plumber Equip. Operator	5.3 18.5 7.0 2.0	4.8
8-in. Cast Iron (7-in. W.C.)	Special shutoff procedures are not necessary at this low pressure.		

TABLE B-2

Repair Estimate - Underground distribution system (12 kV)

	Skill Classification	Repair Effort (mandays)	Total Time Required (8 hr. shifts)
Transformer Bushings Broken - fan Deformation	Electricians (2)	10	5
Transformer Vault Damaged	Cement Worker (2) Electrician (4) Equipment Operator (1)	10 20 10	15
Distribution Ducts and Cables Destroyed (per mile)	Cement Worker (2) Electrician (1) Lineman (7) Equipment Operator (1)	42 32 224 32	32/mile

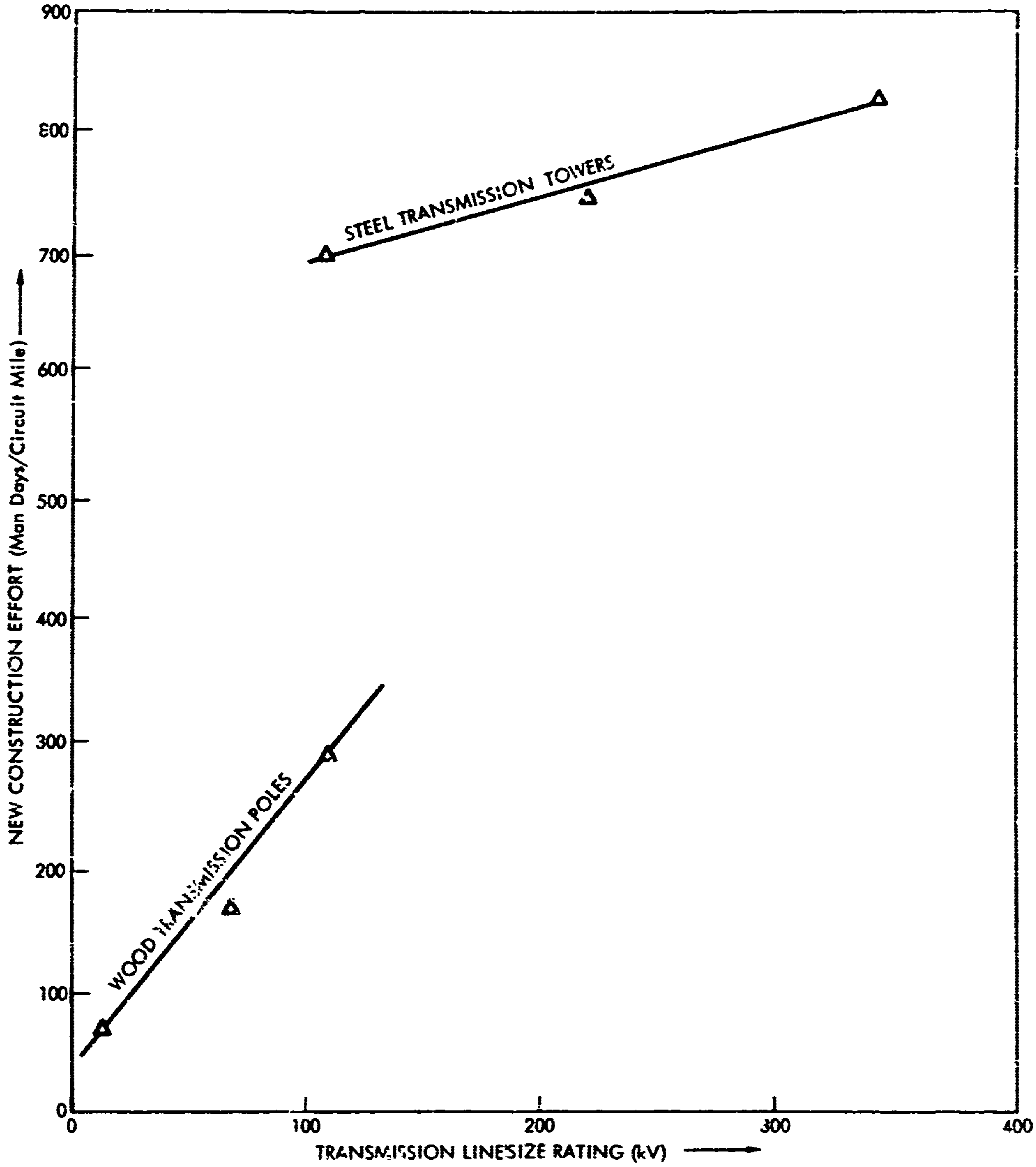


Fig. B-1. New Construction Effort for Various Size Transmission Lines, Electric Utility System

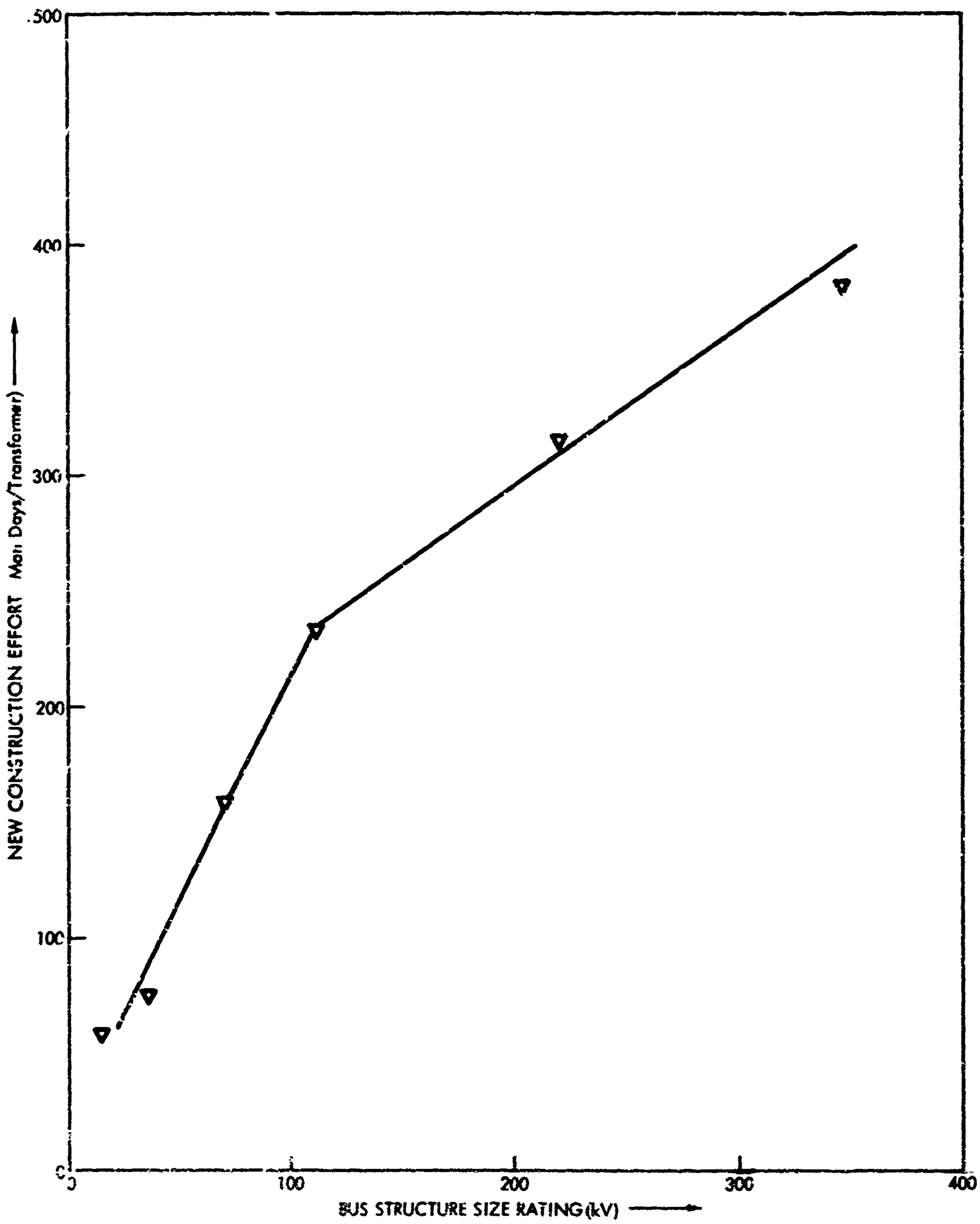


Fig. B-2. Change in New Construction Effort with Variation of Bus Structure Size, Electric Utility System

Appendix C

SELECTED BIBLIOGRAPHY FOR UTILITY OPERATIONS

Appendix C

SELECTED BIBLIOGRAPHY FOR UTILITY OPERATIONS

ELECTRIC

The Babcock and Wilcox Company. Steam, 37th ed., The Babcock & Wilcox Co., New York, 1963.

Knowland, A. E. (ed), Standard Handbook for Electrical Engineers, 9th ed., D. Van Nostrand, Inc., New York, 1953.

Morse, Frederick T., Power Plant Engineering, 3rd ed., D. Van Nostrand, Inc., New York, 1953.

Salisbury, J. K. (ed), Kent's Mechanical Engineers Handbook Vol. II, 12th ed., John Wiley & Sons, Inc., New York 1965.

Skrotzki, G. A. B. and Vopat, W. A., Power Station Engineering and Economy, 2nd ed., McGraw-Hill Book Co., Inc., New York, 1960.

Westinghouse Electric Corp., Electrical Transmission and Distribution Reference Book, 4th ed., Westinghouse Electric Corp., Pittsburg, 1950.

Brookhaven National Laboratories, A Comparison of The Nuclear Defense Capabilities of Nuclear and Coal-Fired Plants, BNL-6080, May 1962.

Electric Light and Power, Cahners Publications Co., Englewood, Colorado. (monthly)

Electrical World, McGraw-Hill Inc., New York, N.Y. (weekly)

Power, McGraw-Hill Inc., New York, N.Y. (monthly)

GAS

Gas Engineer's Handbook - Fuel Gas Engineering Practices, American Gas Association, The Industrial Press, New York.

Katz, Donald C., et al., Handbook of Natural Gas Engineering, McGraw-Hill Book Co., 1959.

Gas Age, Moore Publishing Co., Duluth, Minnesota. (monthly)

Gas Magazine, Chilton Publishing Co., Philadelphia, Pennsylvania. (monthly)

Oil and Gas Journal, The Petroleum Publishing Co., Tulsa, Oklahoma. (weekly)

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) URS Corporation 1811 Trousdale Drive Burlingame, California	2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b GROUP

3 REPORT TITLE

Repair and Reclamation of Gas and Electric Utility Systems

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (Last name, first name, initial)

William H. Van Horn, Gail B. Boyd and Carl R. Foget

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1967	142	25

8a CONTRACT OR GRANT NO. 11205(4949A-65)-US	9a ORIGINATOR'S REPORT NUMBER(S) URS 669-6
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. OCD Work Unit 3311B	

10. AVAILABILITY/LIMITATION NOTICES

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Civil Defense Department of the Army Washington, D.C. 20310

13 ABSTRACT

This study for the Office of Civil Defense has been directed toward identifying the essential subsystems and components of metropolitan gas and electric utility systems, determining their functional relationships, estimating the damage to critical elements from various nuclear weapons effects, and estimating the repair requirements for restoring damaged systems. A mathematical repair model was developed and applied to "typical" city, and from the results of this study, time repair effort including manpower by skills, was derived. The major findings of the report are:

- Being located primarily below ground and comprised of elements having great structural strength, metropolitan gas utility systems tend to be much less vulnerable to weapon damage than electric utility systems. Further, gas system installations are generally less complex in design and function and, therefore, impose smaller and less stringent repair requirements in terms of manpower, skills, equipment, spare parts, and materials.

- The level of damage, expressed as overpressure (and related weapon effects) can be related to repair effort by an experimental function. This mathematical repair model can be used to predict repair requirements (including men and materials under various assumed attack conditions) for real utilities and real cities.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electric Power Systems						
Fuels						
Repair						
Recovery						
Construction						
Repair Scheduling						
Vulnerability						
Analysis						
Weapon Effects						
Labor Performance (Humans)						
Utility Services						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

UNCLASSIFIED
Security Classification